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A RAND NOTE

An Estimation of USAF Aircraft Operating and Support Cost Relations

Gregory G. Hildebrandt, Man-bing Sze

May 1990

RAND

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PREFACE

This Note contains the results of the first phase of our analysis of the availability of data to identify weapon system operating and support costs. The objective of this part of the effort has been to examine how the Air Force's Visibility and Management of Operating and Support Costs (VAMOSC) data base might be used in conjunction with various analytical methods to relate support costs to aircraft. This type of information must be available before DoD can trace the effect on readiness of changes in the total Operations and Maintenance (O&M) budget and estimate the cost of having a particular weapon system in the inventory.

The study was sponsored by the Director of Program Integration, Office of the Under Secretary of Defense for Acquisition. It was carried out by the Acquisition and Support Policy Program under the auspices of the National Defense Research Institute, RAND's OSD-supported federally funded research and development center.

SUMMARY

In an environment of declining defense budgets, obtaining the appropriate balance among the components of U.S. military posture—force structure, modernization, readiness, and sustainability—will be extremely challenging and require careful analysis of the cost reduction alternatives. To analyze readiness, one must be able to relate those resources that affect it to weapon systems. The expenditure on resources that reflects the commitment of DoD to military readiness is called operating and support (O&S) cost, which is incurred as a direct result of operating a weapon system in peacetime.

We believe that a long-term goal of DoD is to understand the readiness effect of force modernization in condition of constrained O&S cost. We are examining what data are available to link O&S cost to USAF aircraft and how these data can be used to approximate the O&S cost of an acquisition program.

The Air Force has developed a data base called VAMOSC that tracks operating and support costs to aircraft mission design series (MDS). In this study, we examine the Weapon System Support Cost (WSSC) of VAMOSC and relate the information in this data base to other Air Force management information systems. We also develop cost estimating relationships that explain the O&S cost of our VAMOSC sample on the basis of aircraft characteristics and operating tempo variables. These relationships might also be useful for approximating the O&S cost of an acquisition program during the early phases of the Planning, Programming and Budgeting System.

We first describe how the O&S cost-accounting system includes sustaining investment activities in addition to the personnel and operations and maintenance categories. Sustaining investment includes expenditures on replenishment spares replacement support equipment, and the acquisition of Class IV modification kits. Although these categories are budgeted in the procurement accounts, they are incurred as a direct result of operating the system in peacetime and fall within the O&S definition.

The relationship between VAMOSC and the Cost-Oriented Resource Estimating (CORE) model of AF Regulation 173-13 and the USAF Force and Financial Plan (F&FP) is also examined. VAMOSC output is based directly on Air Force data, whereas CORE employs planning factors based on averaged and adjusted Air Force data. The F&FP is simply a resource display device that covers fixed and variable O&S costs. It does not

distribute the indirect support costs such as depot maintenance and base support to the individual units. As a result, it is very difficult to assess the total effect of changes in the Air Force budget displays on military readiness.

The greater CORE and F&FP coverage in the sustaining investment area can be expected to lead to some discrepancies between these systems and VAMOSC. For example, VAMOSC, when reporting replenishment spares cost, includes only those spares in the peacetime operating stocks that have been condemned. The procurement of replenishment spares is likely to be greater than condemnations, however, because of the pipeline and stockage requirements. The CORE factors and F&FP have included some of these investments as O&S costs.

We believe that the development of highly aggregative cost estimating relationships to explain operating and support costs is the most innovative part of our analysis. Using VAMOSC data in conjunction with other information on aircraft characteristics, we relate O&S costs per aircraft to flying hours per aircraft, flyaway cost, number of aircraft, and design age. We show that at the total O&S cost level, flyaway cost is an acceptable proxy for aircraft type and the MDS year of initial operational capability (IOC). At lower levels of cost aggregation, the proxy relationship does not always hold and we detail the exceptions.

Increases in flying hours per aircraft and flyaway cost result in less than proportional increases in operating and support costs per aircraft. When total O&S cost is examined, the responsiveness to increases in flying hours is somewhat greater than to increases in flyaway cost; when depot maintenance cost is examined, the responsiveness to increases in flyaway cost is somewhat greater.

Although flying hours remain an important determinant of depot maintenance cost, and although these costs are very responsive to changes in flyaway cost, increases in flyaway cost continue to result in less than proportional increases in depot maintenance costs per aircraft. Also, because one can view depot maintenance as a type of remanufacturing, this result is consistent with the hypothesis that reliability and maintainability improvements lead to a *comparative* reduction in depot maintenance costs.

The analysis of average age of a mission design fleet is set against the backgound of the Air Force's "bathtub" curve hypothesis. This is the belief that early in the service life of an aircraft, O&S costs first decline, then remain stable during a mid-life steady

state period. Eventually, as the end of the service life approaches, the O&S costs begin to rise. Although the cost estimating relationship indicates that there is some tendency for O&S costs to rise as the system ages, we have not found evidence for a downward sloping portion of the cost curve. This may be partly because VAMOSC replenishment spares do not include acquisitions of peacetime operating stocks. These acquisitions have tended to be quite high early in the operating life of a program.

We also identify increases in O&S cost per aircraft with increases in the year of IOC. This effect occurs directly when aircraft type and IOC year are included in the regression and indirectly when flyaway cost is used as a proxy for aircraft type and IOC year.

We have found cost estimating relationships with impressive explanatory results; whether they have equal predictive power remains to be seen. They may be helpful for assessing Air Force tradeoffs between modernization and operating tempo. Eventually, they may also be useful for understanding the cost of achieving alternative readiness levels.

ACKNOWLEDGMENTS

The authors thank Al Barbour and Jim Hodges for their thorough reviews of an earlier draft. The excellent computer assistance by Darlene Blake and secretarial support by Jean Williams is also appreciated.

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I. INTRODUCTION

Operating and support (O&S) costs reflect the commitment of a military establishment to *readiness*. In effect, readiness measures the degree to which a given force structure—the divisions, ships, and airwings—have been "activated" by these expenditures. Currently, there is a concern with the effect on readiness of constrained O&S costs. If these expenditures decline relative to the value of defense assets, it may not be possible to maintain current readiness levels.[1]

A recent study by the Congressional Budget Office (CBO) has highlighted this issue. It examined the relationship between O&S and the capital value of military equipment. Although it estimated several different types of military capital, the analysis centers on the capital value of *major weapons*—that is, the cost in 1988 dollars of major defense items for which there are historical inventory data.[2]

As shown in Fig. 1, between 1975 and 1985, there was a near proportional relationship between O&S costs and the capital value of major weapons. Beginning in 1986, however, O&S costs began to fall below the historical trend. CBO has also indicated that until 1992 the capital value of major weapons is expected to rise at about 3 percent per year; at the same time, O&S costs may increase only about 1 percent per year.

Their analysis suggests that there will be a shortfall between O&S budgets and the costs needed to maintain current readiness levels. This potential problem is accentuated by the limitations of current DoD information systems in relating changes in O&S costs to weapon. For example, a recent study by the General Accounting Office was

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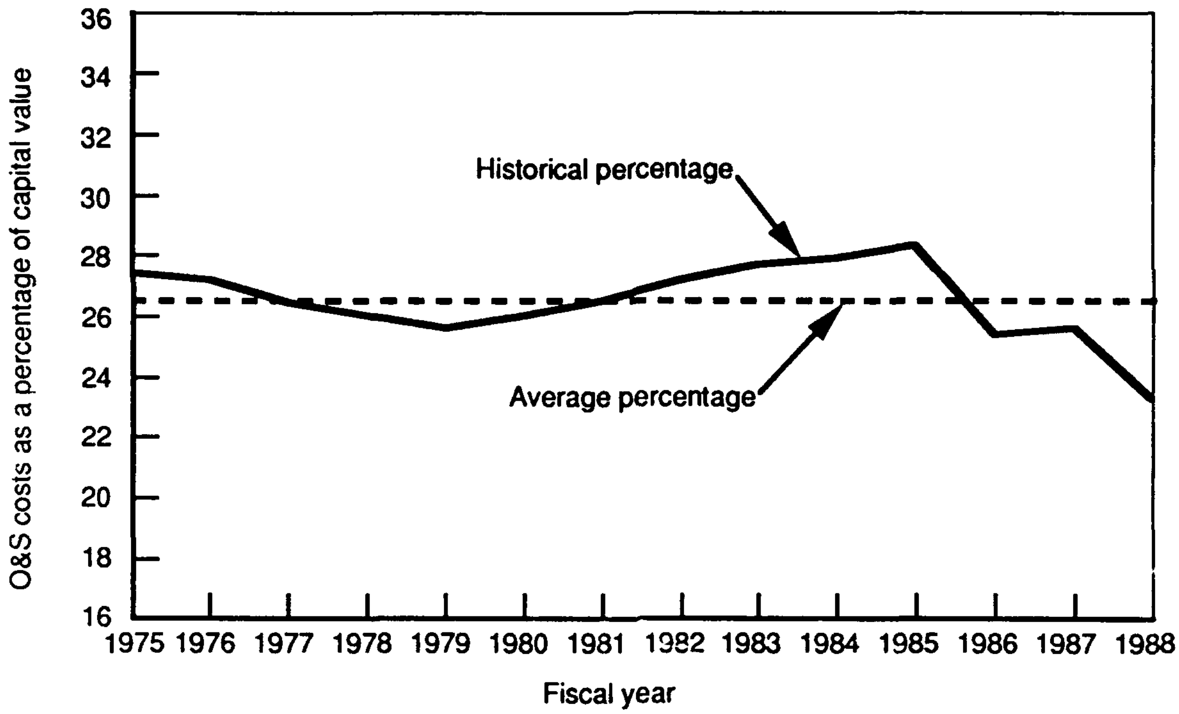
[1]Readiness is defined as "the ability of forces, units, weapons systems, or equipment to deliver the outputs for which they were designed." See *Department of Defense Dictionary of Military and Associated Terms*, JCS Pub. 1, 1 April 1984.

[2]See Congressional Budget Office, *Operation and Support Costs for the Department of Defense*, U.S. Congress, July 1988. Additional capital measures contained in this study are *total weapons*, which includes such investments as missiles, ammunition, and items included in the "other" procurement category. For these items, a perpetual inventory method is used to measure the capital. A third measure, *total DoD assets*, includes the real property possessed by the DoD. CBO defines operating and support costs to include budgetary military personnel plus operations and maintenance (O&M) expenditures. Section II discusses the definition of O&S costs provided by the DoD Cost Analysis Improvement Group (CAIG).



SOURCE: Congressional Budget Office from Department of Defense historical data.

Fig. 1—CBO analysis of capital value and O&S costs

terminated because they were unable to track the O&S costs of selected weapon systems.[3]

A long-term goal of DoD is to understand the effect on readiness of force modernization with constrained operating and support costs. The goal of this project, while more limited than the long-term goal, is an important step toward fulfilling this objective. We have been asked to understand what data are available to link O&S costs to USAF aircraft mission design series (MDS). Clearly, before costs can be related to readiness, it is necessary first to associate the costs with weapon systems.

Our analysis makes use of the data base called Visibility and Management of Operating and Support Costs (VAMOSC) containing MDS operating and support cost data. Several definitional issues hinder comparisons between VAMOSC and other O&S

[3]Letter CC-86-283, from Assistant Comptroller General Frank C. Conahan to The Honorable Lowell Weicker, Jr., May 15, 1987.

cost data bases. We are able to show, however, that VAMOSC can be used with other data to explain how O&S costs relate to aircraft characteristics and operating tempo.

In Sec. II, we first define O&S costs. We also discuss VAMOSC and its relationship to other sources of O&S information such as AFR 173-13 and the USAF Force and Financial Plan (F&FP). AFR 173-13 and the F&FP provide greater coverage in the area of sustaining investment, and we highlight some of the issues associated with replenishment spares.

In Sec. III, we describe how to relate VAMOSC to the flying-hour, operating-tempo variable, and to such aircraft characteristics as flyaway costs. We show that total operating and support costs per aircraft are positively related to both flying hours and flyaway costs. These costs also increase somewhat with the age of a fleet of mission design (MD) aircraft and with the initial operational capability (IOC) year of an aircraft MDS.[4]

The appendix contains a discussion of some additional aspects of the data and statistical analysis employed to arrive at the cost estimating relationship. Specific conclusions and recommendations derived from our study are provided in Sec. IV.

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[4]AFR 173-13, *U.S. Air Force Cost and Planning Factors*, 2 September 1986, provides the following definition for MDS: "An alpha-numeric code used to identify a specific type of aircraft. The mission symbol, a letter, is used to denote the primary function or capability of an aircraft (for example, 'F' in F-4 for fighter). The design number denotes different aircraft with the same function (for example, '4' in F-4 as opposed to '15' in F-15). The series symbol, 'a letter', is used to denote that significant differences exist between related aircraft because of follow on production or major modification (for example, 'C' in F-4C, as opposed to 'D' in F-4D). In certain cases, another letter can precede the MDS designation. This letter is used to indicate that the particular aircraft no longer has the same characteristics as others of the same MDS; (for example, 'R' in RF-4C, as opposed to F-4C). This application is termed 'modified mission symbol.' Another example is 'Y' in YF-4E, as opposed to F-4E. This application is termed 'status prefix symbol.' The modified mission symbol indicates that the aircraft has more or different mission capabilities than others of the same MDS. The status prefix symbol indicates that the aircraft is not in standard configuration and, therefore, not usable in a standard force unit."

II. OPERATING AND SUPPORT COSTS

DEFINITION

The measure of O&S cost employed by CBO, namely budgetary O&M plus military personnel costs, is somewhat different from the measure established by the CAIG. As shown in Fig. 2, O&S costs equal the variable costs incurred as a direct result of operating the system in peacetime.[1]

For aircraft O&S costs, the unit mission personnel would include the aircrews, civilian and military maintenance personnel, and such other personnel as unit staff and security. The installation support personnel category consists of those individuals who, while not directly assigned to the unit, support its activities. Included are personnel involved in base operating support (BOS), real property maintenance, and medical

Variable costs incurred as a direct result of operating the system in peacetime

- Personnel
  - Unit mission personnel
  - Installation support personnel
- Operations and maintenance
  - Unit level consumption
  - Depot level maintenance
  - Indirect personnel support
  - Depot nonmaintenance
  - Personnel acquisition and training
- Sustaining investment
  - Replenishment spares
  - Replacement support equipment
  - Modification kits (Class IV)

Fig. 2—Definition of O&S costs

[1]See CAIG, *Generic Cost Estimating Guide for Operating and Support Costs*, Office of the Secretary of Defense, 25 September 1984. The O&S concept is specialized to aircraft in CAIG *Aircraft Operating and Support Cost Development Guide*, Office of the Secretary of Defense, 15 April 1980.

activities. If the unit were to leave the installation, an identifiable part of the BOS personnel would no longer be required. Therefore, a decision to add the unit to the base would require the addition of these personnel.[2]

Both POL (petroleum, oil, and lubricants) and maintenance material are included in unit level consumption. The maintenance material category contains the non-reparable or reparable items that are not centrally managed. A third category of unit level consumption is training ordnance, which would be funded within the procurement account.

Depot level maintenance includes both overhaul and component repair at DoD centralized repair facilities. A lot of these expenditures would cover the costs of civilian personnel who are employed at the depots. The costs are funded in the O&M accounts.

Indirect personnel support includes various miscellaneous O&M costs such as the cost of temporary duty (TDY) and utilities. Also included in the indirect personnel support category would be the permanent change of station (PCS) cost associated with the relevant personnel categories.

Depot nonmaintenance includes the personnel and material expenditures of the procurement and logistics general depot support functions. It also includes the cost of second destination transportation. This latter category contains the cost of shipping the aircraft or component to and from the depot, and the costs of shipping repair parts from the stock points to the depot or below depot maintenance activities.

Personnel acquisition and training includes the costs of recruitment, ROTC, academy, and such other costs as undergraduate pilot training, undergraduate navigator training, and lead-in-training for fighters. Other officer and enlisted training activities would be included as well.

The O&S concept also contains the sustaining investment expenditures on replenishment spares, replacement support equipment, and Class IV modification kits. Although these expenditures are funded in the procurement accounts, they are costs needed to operate the units in peacetime, justifying their inclusion in O&S.

Replenishment spares include the spares purchased to replenish the inventory of peacetime operating stocks (POS). According to Air Force policy, these stocks are

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[2]Part of the BOS personnel strength is fixed relative to incremental mission units. This part is called the "base opening package": Only the variable portion of total BOS personnel is considered as indirect support attributable to the basing of an incremental unit.

acquired during the procurement of initial spares. The stocks purchased at this time would be used to replace the condemnations. These are the spare parts that are scrapped because it is not cost effective to repair them. The peacetime operating stocks would provide the necessary replacements for spares in the maintenance pipeline. The demand uncertainty that generates these condemnations and repair activities would also be taken into account by including safety levels in the POS.[3]

Although some of the replenishment spares would replace the condemnations, additional demands for replenishment spares are derived from both expected and unexpected changes in the repair activities. These additional demands result from changes in the operating environment, and the spares acquired are considered to be part of the replenishment total.

The procurement of replacement support equipment is also part of operating and support costs because these replacement requirements result from the wear and tear caused by peacetime operations.

Sustaining investment also includes the acquisition cost of Class IV modification kits, which are those required to maintain safety, reliability, and maintainability levels. An example might be the re-skinning of worn areas of an aging aircraft. The rationale for including them in the O&S cost group is that all aircraft periodically are faced with these "safety" mods and their cost may depend on how long they remain in the operating inventory.[4]

Clearly, many cost categories are not included in the O&S definition. The initial one-time costs associated with RDT&E, the acquisition of major weapons, and military construction are excluded. These expenditures support force structure and modernization. War reserve materiel expenditures are excluded because they contribute to sustainability rather than military readiness.

Selected fixed cost elements from the operations and maintenance and military personnel categories are also excluded from O&S costs. For example, base headquarters

[3]This definition of replenishment spares reflects an Air Force policy change. There an interpretation of the change in the letter, "New Initial Spares Definition," from Col. Bruce W. Ewing, Director, Material Requirements and Financial Management, Hq. AFLC to Hq. USAF/LEYS/LEXW, 10 July 1987.

[4]Attrition aircraft might seem to fall in the O&S category as well since the longer the aircraft are operated, the greater the number that will be lost to attrition. However, the replacement aircraft required to offset attrition must be procured early on, while the production line is open. Therefore, they are counted as part of aircraft investment.

and services, the general support overhead expenditures associated with the personnel assigned to HQ AFLC, the general and administrative personnel at the depots, and the overhead expenditures for the training activities would all be excluded. This is because these costs are not viewed as being part of the variable costs of operating the weapons in peacetime. For either incremental force structure or operating tempo changes, one would not expect these types of costs to change very much.

In summary, the O&S concept includes the variable cost elements that support military readiness. All expenditures that support force structure, modernization, and sustainability are excluded. The so-called fixed cost elements—those associated with operating the force in peacetime that do not vary with incremental changes in force structure or operating tempo—are also excluded. O&S, therefore, is a concept that attempts to identify the incremental cost of peacetime military operations.

VAMOSC DATA BASE

Two VAMOSC data bases associated with aircraft that contain cost information at the aircraft MDS level. These are the Weapons Systems Support Cost (WSSC) system and the Component Support Cost System (CSCS). In this study we focus on WSSC.[5]

The WSSC employs the definition of O&S cost established by the DoD Cost Analysis Improvement Group. Currently, however, there are several categories of O&S not yet included in the VAMOSC WSSC. The major categories discussed above, which are missing from WSSC, are replacement support equipment, second destination transportation, and personnel acquisition and training.

When the VAMOSC data base was established, it was specified that all input data be obtained from existing Air Force management information systems. Thus, data are obtained from such systems as the Accounting and Budget Distribution System (ABDS), which identifies below depot level operations and maintenance expenditures; the Weapons System Cost Retrieval System (WSCRS), which contains depot level costs; and the GO33B Aerospace Vehicle Inventory Status/Utilization Report, which gives individual USAF active aircraft, flying hours, possessed hours, possessing organizations,

[5]The CSCS contains information on reparable subassemblies and components at the MDS level from 1987 to the present. It uses a cross reference between the national stock numbers and the work unit codes that has recently been developed. Although we haven't analyzed CSCS in detail, we believe that this data base may have a role in analyzing some of the costing issues associated with WSSC.

and locations of aircraft at any given time. This latter data base is used to determine, for any specified period, the average number of aircraft possessed (owned) by each command and the associated flying hours.[6]

Historical aircraft MDS data are available in VAMOSC from 1981 to the present. Not all costs, however, are directly collected at the MDS level; some must be allocated. The necessary cost allocations are typically based on flying hours and number of aircraft and reflect an attempt to identify the marginal cost of some activity. As an example, depot maintenance on-equipment aircraft overhaul costs, which constitute about 40 percent of VAMOSC depot maintenance costs, are collected at the MDS level. The cost associated with the maintenance of components that are common to more than a single aircraft MDS is not currently identifiable by MDS; the associated costs are allocated to MDS using the number of aircraft in inventory and the associated flying hours. The appendix contains additional discussion of the cost allocation issue.[7]

Information on the actual and potential information flow that exists between VAMOSC and other Air Force data bases, as indicated in Fig. 3, is available from the various Air Force management information systems. Not only is the information in these data bases used to determine both the WSSC and CSCS operating and support costs of VAMOSC, but it is also used to construct the planning factors of AFR 173-13. This regulation also contains the associated CORE model that employs the planning factors for estimating squadron operating and support costs.[8]

An important issue is the potential for an increased use of VAMOSC data in the development of O&S planning factors, so we have drawn a solid line from VAMOSC to AFR 173–13. Also, because there is an interest in understanding the cost basis behind Air Force budgets, solid lines have been drawn from VAMOSC and AFR 173-13 to the USAF Force and Financial Program (F&FP). The lines drawn suggest that the consistency of data among VAMOSC, AFR 173-13, and the F&FP is an issue of concern.

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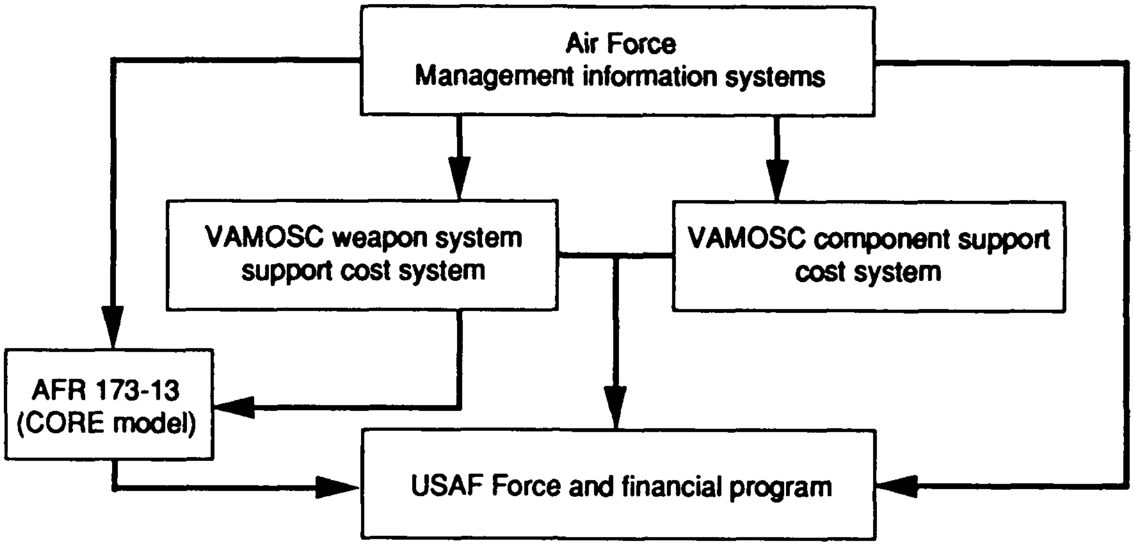
[6]VAMOSC does not contain data on Primary Aircraft Inventory (PAI). It records aircraft "possessed" by the commands. It is important to remember this point when associating VAMOSC data with aircraft quantities in planning exercises.

[7]The data bases used in VAMOSC and the allocation rules are discussed in *Executive Summary for VAMOSC*, Office of VAMOSC, Hq. AFLC/ACCV, Wright-Patterson AFB, OH, January 1987; and AF Regulation 400-31, Volume II, *Visibility and Management of Operating and Support Cost Program: Weapons Systems Support Costs (WSSC)*, 24 August 1982. Volume IV of this regulation discusses CSCS.

[8]For a discussion of the planning factors and the CORE model, see AFR 173-13. These factors are updated annually.



NOTE: Consistency of data is issue of concern.

Fig. 3—Information flow between VAMOSC and other Air Force data bases

VAMOSC AND CORE

VAMOSC is an Air Force data base of actual expenditure data, and the CORE model employs planning factors based on averaged Air Force data to estimate "typical squadron" costs.[9]

Several O&S categories included in CORE are currently excluded from VAMOSC. The most important of these is probably personnel acquisition and training. According to the CORE model, this category accounts for approximately 10 percent of the O&S costs for fighter and attack squadrons; perhaps 5 percent of the O&S costs for cargo squadrons would be associated with this category.[10]

[9]The only planning factor of AFR 173-13 that is directly estimated from VAMOSC is the life-cycle factor for base maintenance supplies. To estimate this planning factor for a new aircraft, the Air Force Cost Center first selects a base maintenance supplies cost per Primary Aircraft Authorized (PAA) from a relevant predecessor aircraft. This ratio is assumed to be applicable during the early years of service life. At some point during the service life, say the 16th year, the factor is assumed to begin to rise. As VAMOSC data are collected for the new aircraft, they are compared with the historically determined relationship. The cost per PAA is then increased or decreased if the VAMOSC base maintenance supplies cost is judged substantially different from the historical levels.

[10]The combat crew training squadrons (CCTS) possessed by the operational commands are contained in the VAMOSC command and base totals. No effort is made to separately identify these activities as training or allocate their costs to the operational units.

A second excluded category is replacement support equipment. No existing data base permits one to identify, for each aircraft type, the ground support equipment that is retired each year. Such information would be needed to incorporate this category into VAMOSC. This category is, however, estimated for AFR 173-13 using available inventory data on most of the ground equipment. Given knowledge of the cost of this equipment and an assumption of service life, the AFR 173-13 planning factors are estimated by dividing the total value of replacement support equipment acquired over the service life of an aircraft by that aircraft's service life.[11]

In the replenishment spares area, VAMOSC collects information only on annual condemnations. The CORE model factor, in contrast, includes a squadron's total procurements of replenishment spares during the budget year based on both condemnations and an updated estimate of the POS needed to support repair activities. This latter component is particularly important during the early years of a new weapon system.

One of the major reasons why total procurements differ from the eventual condemnations is that there are both expected and unexpected elements in the underlying data base used to determine requirements. Clearly, annual condemnations are one of the factors that affect the spares requirements, and repair activities affect the requirements generated both by spares being in the maintenance pipeline and by the stockage level safety requirements induced by the stochastic nature of demands.

A RAND study indicates that a substantial part of the replenishment spares requirements are unexpected, resulting from the dynamics or "churn" in the data base used to estimate requirements. For example, force structure and the flying hour program may change unpredictably. Also, the nature of the repair items might change because of modifications that make some of the existing parts inventory obsolete. These factors

[11]The C008 data base has detailed information available on ground support equipment authorized to be in use and its associated cost. To determine the AFR 173-13 budget year factor for a particular MD aircraft, one calculates the number of times the ground support equipment of the C008 data base will be replaced during the service life of the relevant aircraft. This permits one to approximate the total dollar acquisitions of replacement support equipment needed for each aircraft MD. Then, one divides the service life of the aircraft into this total to determine the average expenditure per year.

generate a shortage of many repair items and increase the quantity of replenishment spares that need to be procured.[12]

With respect to the acquisition costs of Class IV modification kits, CORE uses a cost estimating relationship that relates the annual cost of these kits to aircraft flyaway cost. VAMOSC collects historical cost data, but we believe that there were substantial improvements in the quality of the VAMOSC data beginning in 1985 when the WSCRS data base was used to obtain information for this category. However, as discussed in the appendix, there is evidence that the VAMOSC coverage of this category was incomplete before that year.[13]

Finally, as discussed earlier, VAMOSC does not collect data on replacement support equipment. There is no Air Force data base that identifies the ground support equipment "used up" by aircraft type during annual operations. However, both the F&FP and AFR 173-13 approximate these costs by type of unit on the basis of overall Air Force procurement of these support items.

VAMOSC AND USAF FORCE AND FINANCIAL PROGRAM

VAMOSC and the USAF F&FP have different purposes. VAMOSC measures the variable cost of operating the units, whereas the F&FP is a resource display device for programmed dollars and often combines both fixed and variable costs. The F&FP also retains a distinct separation between resources that are programmed for the operating forces and those that are programmed for such indirect support activities as base support, depot maintenance, and training. The costs associated with these indirect support activities are not distributed to the aircraft MDs. It is possible, however, to crosswalk between many of the costs covered by the O&S categories of VAMOSC and the categories of the F&FP.[14]

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[12]See J. Abell et al., *The Cost and Performance Implications of Reliability Improvements in the F-16A/B Aircraft*, The RAND Corporation, N-2499-AF, March 1988. They estimate that churn alone can account for 16 to 21 percent of the total costs of all the spares in the system. Because all spares acquired include the initial spares procurement, churn would account for an even larger percent of replenishment spares.

[13]The WSCRS data base is discussed in AFLC Manual 173-264, *Weapons System Cost Retrieval System (WSCRS)(H036C)*, 3 October 1983.

[14]In the area of sustaining investment, the crosswalk would be more difficult because these categories are procurements and the obligation authority in the F&FP would have to be lagged by an appropriate adjustment factor to account for the fact that expenditures tend to lag procurement obligation authority by a year or more.

In Fig. 4, we describe what types of comparisons can be made. For some cost categories, O&S information is available in the F&FP only for Air-Force-wide totals. For another set of categories, the F&FP contains information for total aircraft. There is, however, a set of O&S categories for which F&FP information is available at the MD level.[15]

Section 1 of the figure shows that installation support personnel, indirect personnel support, and depot nonmaintenance are primarily available in the F&FP for Air-Force-

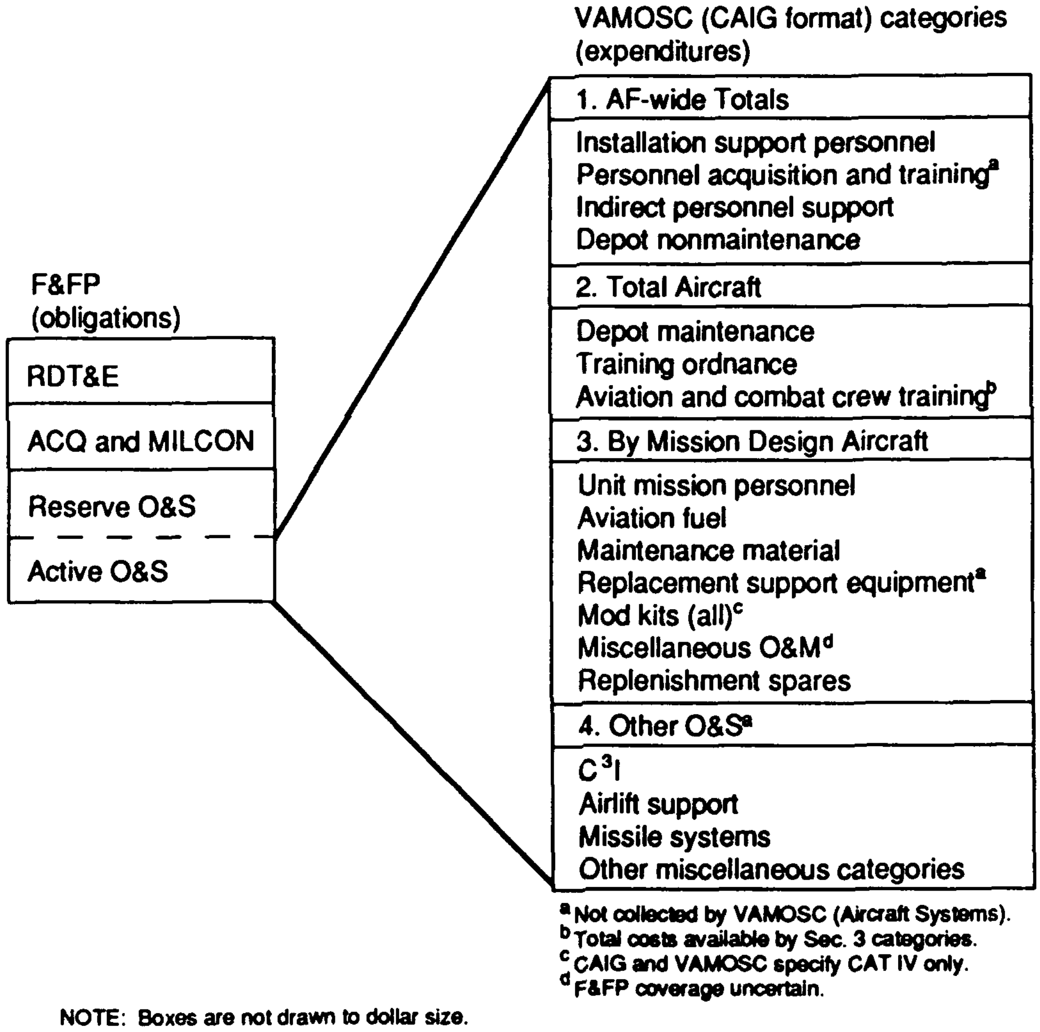

Fig. 4—USAF F&FP vs. VAMOSC comparisons

[15]Gary Massey of RAND provided us with a description of these relationships.

wide totals. Therefore, it is not possible to crosswalk between VAMOSC and the budget document in these areas. Also, as indicated, while there are total Air-Force-wide personnel acquisition and training data in the F&FP, such data are not available in VAMOSC.

There are several O&S categories for which information is available in the F&FP at the total aircraft level. Section 2 of Fig. 4 shows that these are depot maintenance, training ordnance, and a budget total for aviation and combat crew training. The depot maintenance totals in the F&FP include the general and administrative overhead expenditures. As fixed cost elements, these are excluded from VAMOSC.[16]

Section 3 of Fig. 4 identifies the O&S categories for which F&FP information is available at the MD level. At the present time, it is not possible to identify the part of the F&FP total associated with the acquisition of Class IV modification kits. The F&FP contains *all* budgeted modification kit data at the MD level. The O&S concept, however, counts only Class IV modifications as part of O&S. The Class III and V modifications that enhance the performance level of the system are not included in VAMOSC.

In the area of replenishment spares, the same issues discussed earlier when comparing VAMOSC and CORE continue to apply. VAMOSC, which takes a consumption view of cost, contains only condemnations; the F&FP includes all programmed spares procurement during a given year including that resulting from anticipated changes in the underlying cost drivers. We would expect, therefore, VAMOSC to be considerably lower than the F&FP in this area, particularly in the years immediately following IOC.

We can also identify the categories in Sec. 3 of the figure for crew training activities only as the combined total for all aircraft in the command. The issue with this category is that the F&FP totals for a particular MD are limited to the costs associated with the operational squadrons. VAMOSC, however, collects information on all aircraft assigned to a command, by MDS, and does not distinguish between those that are in training and those that are in operational squadrons. To compare the two data bases, therefore, it is necessary to somehow disaggregate the F&FP information using, say, the flying hour activities of the various training squadrons.

Once again, we are reminded by this figure that VAMOSC does not now contain information for replacement support equipment ruling out a comparison with F&FP for

[16]While installation support personnel data are associated with Air Force Commands, some of this personnel might actually support non-command tenant organizations. Also, aviation and combat crew training data are available at the Air Force command level.

this category. Finally, although there is data in the F&FP at the MD level for miscellaneous O&M, which is actually part of the indirect personnel support category, we are not certain whether this category is comparable to the VAMOSC miscellaneous O&M. In the VAMOSC O&S system, this category includes the cost of TDY (travel and per diem), utilities, purchased services, and miscellaneous supplies and equipment.

There are a range of definitional issues that complicate comparisons between the two systems. Because associating total costs and weapon systems is a necessary step for understanding the full effect of budgets on readiness, the Air Force budget displays are not well-suited for analyzing their effect on readiness. Ultimately, to understand the readiness implications of the budget displays, one must have access to the inputs that underlie the financial figures.

With the exception of the areas noted above, however, the VAMOSC system provides coverage of the categories identified by the CAIG as constituting operating and support cost. This comprehensive data base merits consideration for use in the development of relationships that explain O&S cost using aircraft characteristics and operating tempo variables.

III. O&S COST ESTIMATING RELATIONSHIP

We turn now to the issue of whether VAMOSC O&S costs can be related to key explanatory variables. Several steps must be taken to develop an empirical model using this data base. First, it is necessary to examine the VAMOSC data to insure that the data employed in the cost estimating relationship are comparable. Incomplete O&S cost data series must be eliminated or, where feasible, completed using information from other sources. Second, the data base must be supplemented with information on potential key variables not contained in VAMOSC. Finally, one must specify and estimate the empirical relationships.

SCREENING AND SUPPLEMENTING VAMOSC DATA

To obtain consistency of the data over the 1981–1986 time period, certain data points and cost elements were eliminated from VAMOSC: helicopters, obsolete aircraft, and full-service contract aircraft. There are several full-service contract aircraft, such as the C-9 and C-12, for which contractors conduct all depot maintenance activities. Because VAMOSC does not contain any of this cost information, these aircraft were removed from the data base.

We also eliminated helicopters and obsolete aircraft. This latter category includes aircraft such as the B-52D for which no flying hours were reported beginning in 1985, but that may continue to be used in ground training activities.

We have eliminated the costs associated with the acquisition of Class IV modification kits. As indicated above, we believe that the information collected for this category was deficient before 1985. We decided, therefore, to exclude these expenditures from VAMOSC when developing the cost model.

We also discovered that VAMOSC unit mission personnel data do not take account of the accrual cost of military retirement for 1981–84. Therefore, we adjusted the data to make these early years comparable with the data for 1985–86. Because the installation support personnel category has not accounted for military retirement costs over the entire 1981–86 period, we also adjusted this category to make the totals comparable with unit mission personnel.

Table 1 summarizes the aircraft mission design series totals in the retained data base. Note that there are from 62 to 74 different aircraft mission design series over the estimation period. We call these observations because yearly data are available for each aircraft mission design series. The data for a specific aircraft MDS in a particular year represents one observation in the estimation of the cost estimating relationship. As shown, the data base contains 400 observations.

Approximately one-half of these MDS are cargo aircraft; somewhat less than one-half of the MDS are fighter/attack aircraft. The "other" category amounts to less than 15 percent of the total and includes the bombers in addition to such categories as trainers and observation aircraft.

Total O&S costs in the retained VAMOSC data are summarized in Fig. 5. We can see that in 1986, there are approximately $15 billion for costs collected. For comparison the Air Force budget was approximately $100 billion that year.

The pay and allowances category, which includes civilians in the unit mission personnel and installation support personnel categories, constitutes about half of the VAMOSC O&S total. The "other" cost category includes replenishment spares, maintenance materiel, training ordnance, indirect personnel support, and general depot support.

We have supplemented the VAMOSC data with information on the aircraft flyaway cost, average mission design age, and the mission design series year. The average mission design age is sometimes called the average age of the mission design fleet; the MDS year represents the year of IOC for new aircraft MDS. The VAMOSC information, which is collected in then-year dollars, has also been converted to 1986 dollars using price deflators from AFR 173-13.

Table 1

RETAINED OBSERVATIONS IN THE VAMOSC DATA BASE

Year	Cargo	Fighter/Attack	Other	Total
1981	30	23	9	62
1982	29	25	9	63
1983	30	25	9	64
1984	33	25	9	67
1985	34	27	9	70
1986	36	27	11	74
All years	192	152	56	400

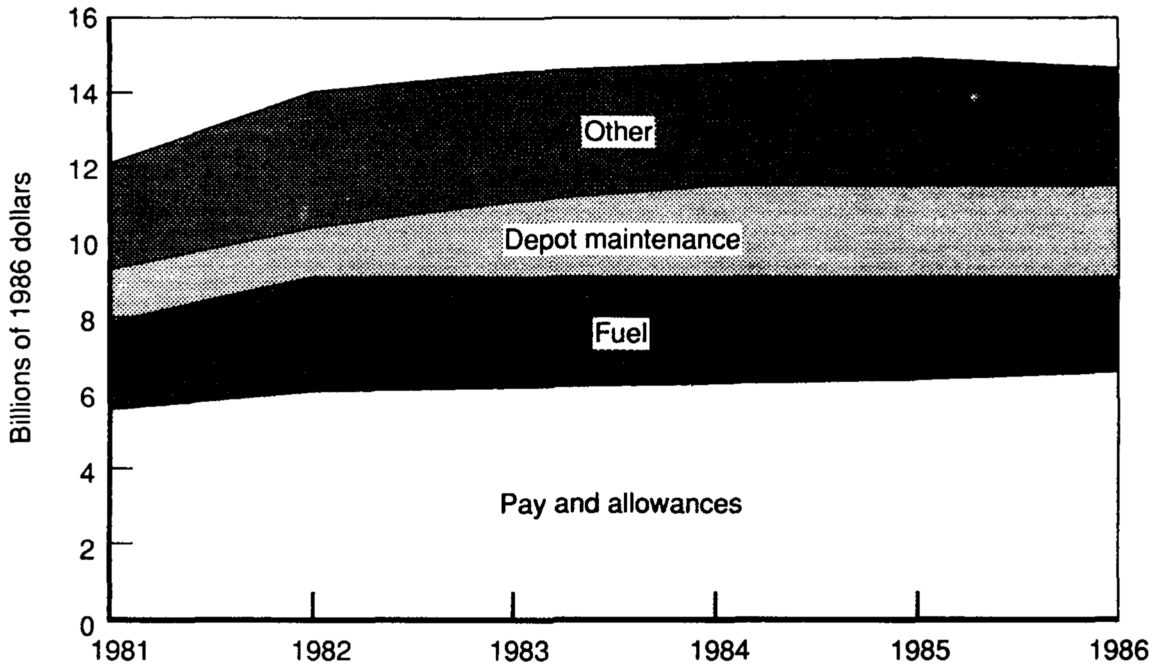

Fig. 5—Total O&S costs for retained VAMOSC data

It is helpful to examine several plots of the data points. Figure 6 contains a log-log plot of O&S cost per aircraft versus flying hours per aircraft. For ease in presenting data points, the data are grouped into flyaway cost and design age categories. A data point represents the average O&S cost per aircraft and the average flying hours per aircraft of all aircraft whose flyaway cost and design age falls within a particular range.[1]

Even when one does not use a cost model to control for the effect of variables other than flying hours, there is evidence of an association between the two variables. Notice that the outliers are the low O&S cost trainers and observation aircraft.

Some part of VAMOSC O&S costs are allocated to aircraft MDS using flying hours and the number of possessed aircraft. These allocation rules are an attempt to identify the marginal O&S cost with respect to these variables. To the extent that the allocation rules fail to reflect marginal cost, the identified association could be

[1]This data-grouping procedure does tend to suppress some of the data variability. Because there are 400 observations, however, some type of grouping procedure is necessary to display the information. The multiple regression technique used to develop the cost model explicitly computes the proportion of the variation in operating and support cost per aircraft explained by the model. This proportion is called the R.

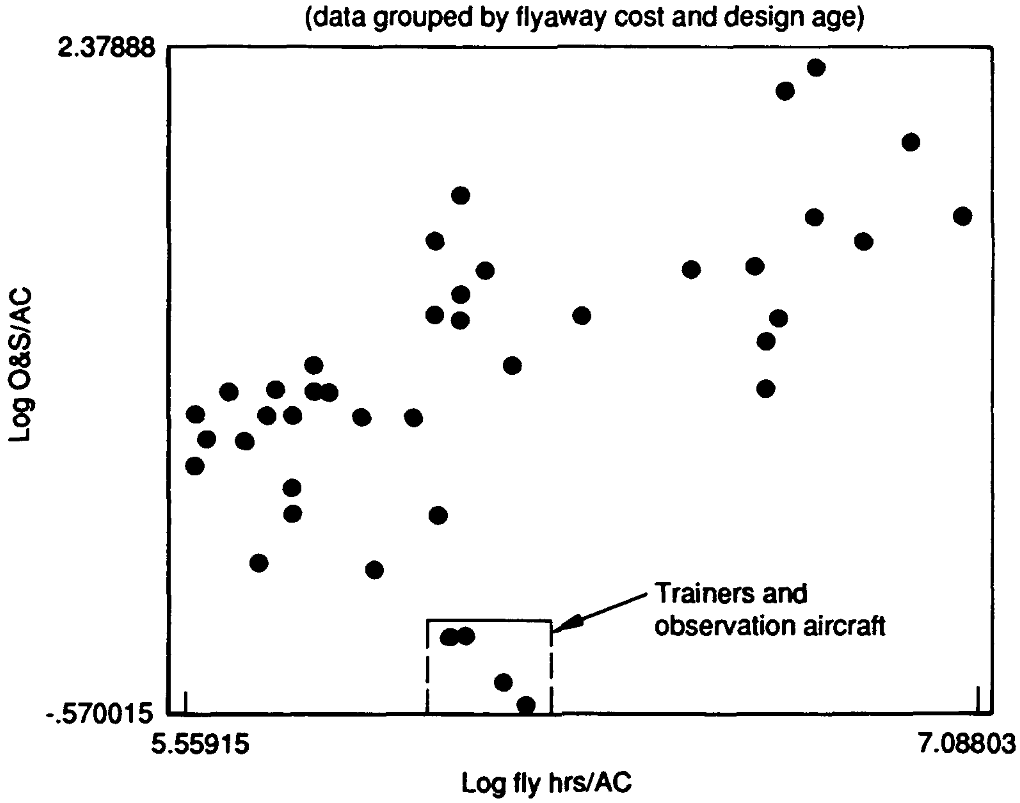

Fig. 6—O&S/AC versus flying hours/AC—1981–1986

misleading. Our discussion of cost allocation in the appendix, however, indicates that the association presented in Fig. 6 is real and not an artifact of the allocation rules.

O&S costs are not allocated to aircraft MDS based on flyaway cost. Yet, as indicated by the data presented in Fig. 7, the association is even stronger between O&S cost per aircraft and flyaway cost.

Another issue that is very important to understand is the nature of the aircraft inventory measure contained in VAMOSC. As discussed above, VAMOSC contains aircraft possessed or owned by the command. In many planning exercises, one is interested in relating O&S costs to PAA.[2]

[2]According to AF Regulation 173-13, PAA equals the aircraft authorized to a unit for performance of its operational mission. In contrast, PAI is defined as the aircraft assigned to meet the primary aircraft authorization. As discussed in the appendix, there are some differences between the possessed aircraft of VAMOSC and PAI during 1986. The correlation between the two series is quite high, and regression results obtained when PAI aircraft are substituted for VAMOSC possessed do not change very much.

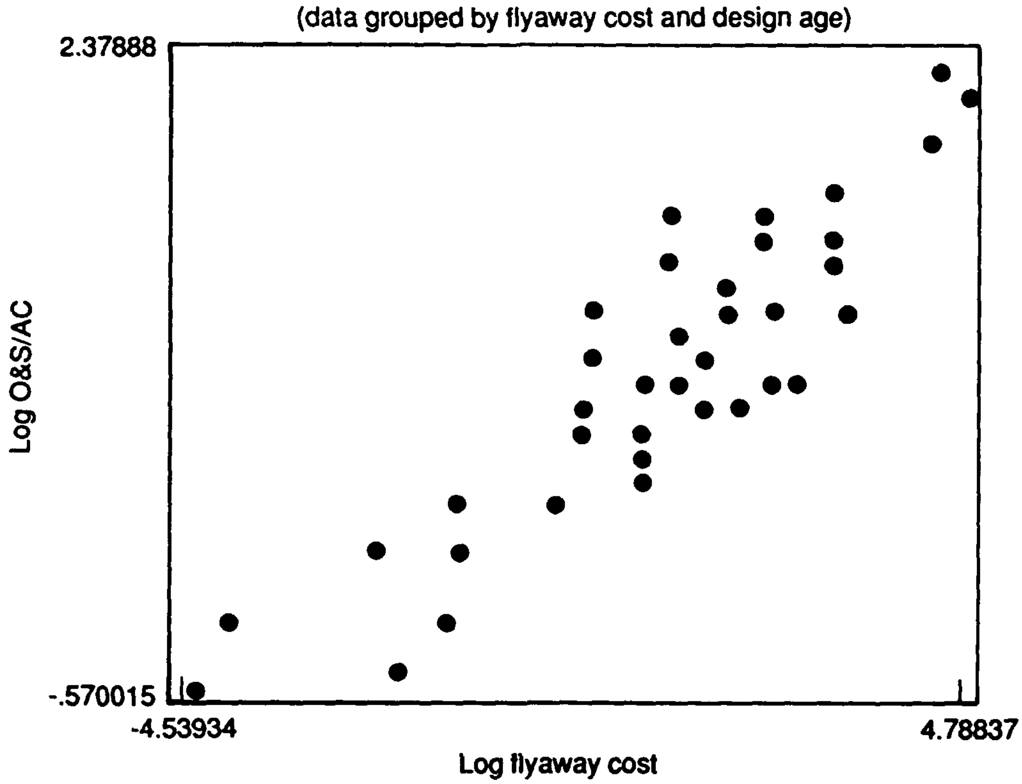

Fig. 7—O&S/AC versus flyaway cost/AC—1981–1986

SPECIFICATION AND ESTIMATION OF EMPIRICAL RELATIONSHIPS

In the light of the associations identified in Figs. 6 and 7, it is reasonable to hypothesize that O&S costs per aircraft are affected by flying hours per aircraft and flyaway cost. The logic of military operations also indicates that these variables and such others as the number of aircraft and the average age of a mission design fleet may affect O&S costs as well.

An increase in the flying hour program, in support of personnel readiness, can be expected to increase many military consumption activities. Fuel expenditure increases and greater quantities of replenishment spares, maintenance material, and support equipment are consumed. There should also be greater requirements for depot activities.

Greater flying and maintenance activities increase the level of readiness of existing personnel, but there might also be a greater demand for maintenance personnel.[3] This would increase the requirements for personnel acquisition and training, and also possibly for installation support personnel and indirect personnel support. To attract these people to the military, it may even be necessary to raise pay and allowances.

While it is also natural to expect O&S costs to vary with the number of aircraft, the dependence of O&S costs *per aircraft* on the number of aircraft is more ambiguous. There may be some economies of scale that permit maintenance activities to be conducted at lower cost per aircraft as one increases the size of a fleet. With larger numbers of aircraft, more efficient repair and test equipment is likely to be acquired at both the base and the depot. In addition, as aircraft per base increases, there would be greater opportunity to share resources.

Because maintenance activities represent a kind of remanufacturing, one would expect O&S costs for an aircraft fleet to vary with the flyaway costs. As aircraft become more expensive, the cost of the replenishment spares and maintenance and test equipment is also likely to increase. It is uncertain whether O&S costs per aircraft will increase proportionally with flyaway cost. Part of an aircraft's flyaway cost can be associated with enhancements in reliability and maintainability, and this may somewhat offset the cost increases associated with maintaining a more expensive aircraft.

Without a careful examination of data, however, it is unclear to what extent flyaway cost can act as a proxy for the specific physical attributes of different aircraft such as number of engines, percentage of cost devoted to electronics, density of the electronics, and so on. The flyaway cost implications of each of these factors may or may not have a differential effect on O&S costs. The data must ultimately do the talking in this area.

As a fleet of mission design aircraft ages, one may hypothesize that initially O&S costs decline as learning takes place and the initial reliability and maintainability problems are eliminated. The introduction of the Class IV modification kits may, on ı: aid these cost reduction activities. One may also hypothesize, however, that as the equipment ages, there will be greater requirements for maintenance and repair activities.

[3]To the extent that peacetime maintenance is based on high wartime flying requirements, an increase in peacetime flying hours would not necessarily result in an increase in maintenance personnel. Existing personnel could be used more intensively.

One would expect that this latter phenomenon will be tempered by the depot maintenance activities.

As shown in Fig. 8, there is an Air Force view that the O&S costs of a system first decline early in the service life as learning takes place and the requirement for additions of replenishment spares to the peacetime operating stocks declines. One then moves to the "mid-life steady state" period when O&S costs remain fairly level. As the system continues to age, however, these costs, presumably from such O&S categories as replenishment spares and depot maintenance, eventually rise fairly rapidly in a "bathtub" curve, and the concept is used as an aid to develop some of the planning factors of AFR 173-13. We use the cost model to determine whether there is empirical evidence supporting this belief about O&S costs.

Other explanatory variables might also be considered in the cost model. For example, it is useful to investigate whether the type of aircraft, say fighter-attack versus cargo, affects O&S cost over and above what occurs through changes in flyaway cost.

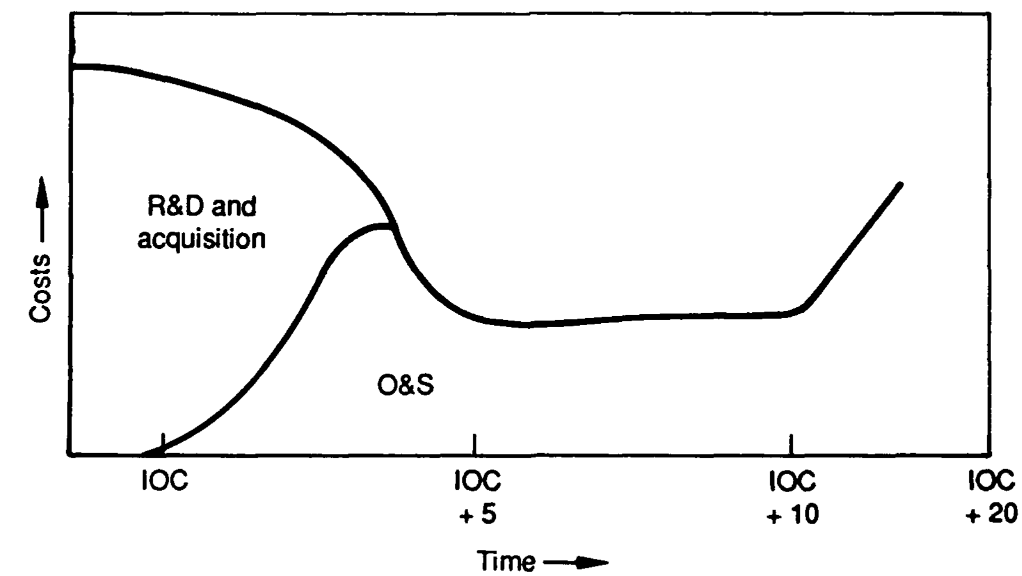

Fig. 8—Air Force view of life-cycle costs

Also, the MDS IOC year may affect O&S costs directly as well as indirectly through its effect on flyaway cost.

Figure 9 indicates that there are four major categories of O&S costs used to define selected dependent variables. One dependent variable—the bottom line—is total O&S cost per aircraft. This total consists of pay and allowances (P&A), fuel, depot maintenance, and other support categories. As indicated above, the "other" support category includes replenishment spares, maintenance materiel, training ordnance, indirect personnel support, and general depot support.

We define additional dependent variables by peeling away the O&S onion until we finally reach depot maintenance costs. Our primary interest in this study is with total O&S costs and with the nonpersonnel, nonfuel O&S cost components. While a different modeling methodology might be appropriate to address personnel and fuel costing issues, it is interesting to examine how the model for the total continues to apply when one removes these and other categories.

Pay and allowances are first removed to arrive at a second dependent variable called non-P&A O&S. Next, fuel costs are eliminated to obtain the variable, non-P&A, nonfuel O&S. Finally, the other expenditures are removed to obtain the cost of depot maintenance activities as our final dependent variable.

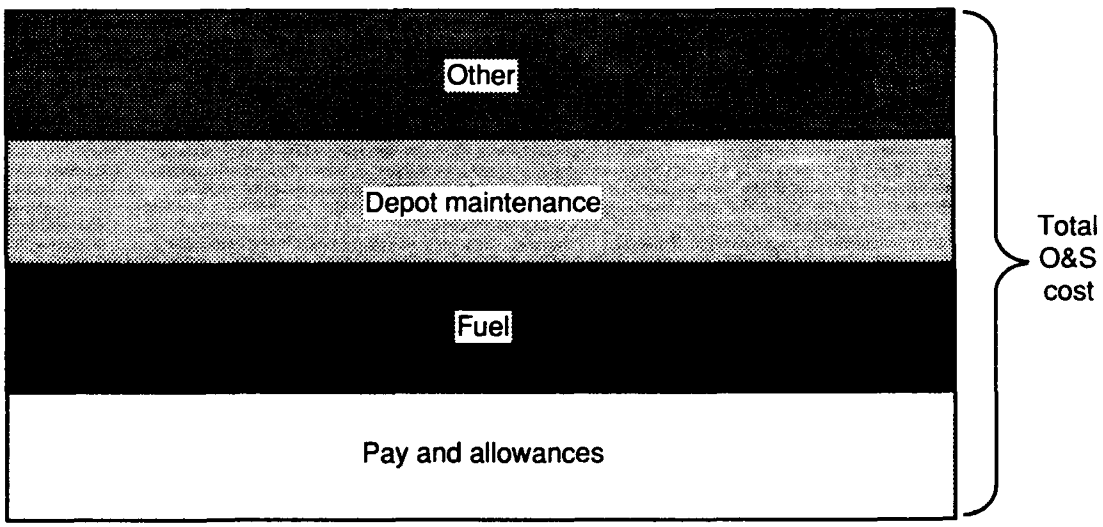

Fig. 9—Components of dependent variables considered in cost model

LOG-LINEAR REGRESSION MODELS

Using the data discussed above, we examine the relationship between O&S costs and these types of variables using a log-linear model. Given the nature of O&S costs, any regression model is likely to be an approximation of some underlying relationship that is both nonlinear and contains important interactions among the explanatory variables. A log-linear model is a first-order approximation (in the logs) of such a relationship. Its multiplicative functional form (after taking anti-logs) also reflects interaction among the variables. As a result, the effect of a particular explanatory variable on O&S cost depends on the values of the other explanatory variables. This type of interaction would not be obtained in a linear model.

Another advantage of the log-linear model derives from the ease in interpreting the regression coefficients. Since the coefficients of each variable in this model are interpreted as the percentage change in the dependent variable resulting from a 1 percent change in the explanatory variable, the units of measure for the variables become unimportant. As a result, measurement errors that do not affect the growth rates of the variables have no affect on the estimated coefficients of the explanatory variables.

An additional advantage of a log-linear model is that it can reduce a potential problem with heteroscedasticity. For example, if the variance of the error term is correlated with the total number of aircraft in a particular MDS, the ordinary least squares estimation technique would yield estimates that are inefficient, although they would remain unbiased. The log-linear model, however, attenuates any correlation between the error term and explanatory variables.[4]

ESTIMATED RELATIONSHIPS

We now examine the results obtained when the different levels of O&S cost aggregation depicted in Fig. 9 are employed. As we are interested in determining whether major categories of aircraft have an independent effect on operating and support costs, we explicitly identify fighter-attack aircraft and cargo aircraft using categorical

[4] Our analysis of the regression results indicated that this in fact occurred. Both an examination of regression residuals and the use of the Goldfeld-Quandt test indicated that the problem of heteroscedasticity was minimal in the log-linear model. For a discussion of how a log-linear model can attenuate a heteroscedasticity problem, see Damodar Gujartari, *Basic Econometrics*, 2nd Ed., McGraw Hill, New York, 1988.

variables. The effect of a further division of aircraft into fighters, attack, nonmodified cargo and modified cargo is discussed in the appendix.[5]

Table 2 contains the results of three regressions in which the dependent variable is total O&S cost per aircraft. In the All Variables column, we report the results obtained when total O&S cost per aircraft is regressed on all explanatory variables identified in the table. The fighter-attack and cargo categorical variables and MDS IOC year are not statistically significant in this regression. As flyaway cost is very strongly statistically significant, it is appropriate to explore the extent to which flyaway cost can be viewed as a proxy for aircraft type and MDS IOC year.

In the next column, Flyaway Only, we remove the categorical aircraft type variables and MDS IOC year, which are statistically insignificant in the first regression. The coefficients of the variables retained in the Flyaway Only regression remain statistically significant and have not changed in value very much. Notice also how the R^2 of this regression, .82, is the same as in the first regression. The implication is that the categorical variables and MDS IOC year explain very little of the variation in O&S costs. These factors—the significance and stability of the coefficients of the retained variables and the small change in R^2—increases confidence in the use of aircraft flyaway cost as a proxy for aircraft type and MDS IOC year.

We also show in the Flyaway Only regression that a 1 percent larger flying hours per aircraft input results in total O&S cost per aircraft that is higher by .61 percent; a 1 percent increase in flyaway cost increases O&S cost per aircraft by about .39 percent. Total O&S cost per aircraft, it seems, is more responsive to increases in aircraft flying hours than to increases in flyaway cost.

Also note in the Flyaway Only column that a one year increase in the MD fleet age increases total O&S cost per aircraft by about 1.7 percent. As an aircraft ages, O&S costs tend to increase. As is discussed further in the appendix, we have not found any tendency for O&S costs per aircraft to decline during the early years of service life as depicted in Fig. 8.

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[5]As discussed in the appendix, in addition to examining alternative functional forms, we have also examined the stability of these relationships over time. We conclude that the estimated relationships are quite stable. There may not, therefore, have been significant changes in the coverage of retained VAMOSC data throughout the sample period.

Table 2

REGRESSION OF TOTAL O&S COSTS
(t-statistics in parentheses)

Dependent Variable: Log of Total O&S Cost per Aircraft			
Independent Variable	All Variables	Flyaway Only	No Flyaway Variable
Log average flying hr	.623 (15.800)	.6142 (20.353)	.6543 (10.047)
Log number of aircraft	−.0413 (−3.863)	−.0381 (−3.996)	−.0552 (−3.129)
Log flyaway cost	.3975 (26.077)	.3918 (27.269)	—
Fighter-attack	−.0014 (−0.026)	—	.1728 (1.841)
Cargo	−.0044 (−0.078)	—	.262 (2.850)
MDS IOC year (1944 = 1)	−.0042 (−1.281)	—	.0163 (3.089)
MD fleet age	.0134 (3.203)	.0171 (7.224)	.0269
Intercept	−3.751 (−13.504)	−3.854 (19.853)	−3.695 (−8.056)
Adjusted R_2	.82	.82	.51
No. Observations	400	400	400

We do not make very much of the significance of the coefficient of number of aircraft. Because the dependent variable is O&S cost per aircraft, the low value of this coefficient indicates that O&S costs are nearly proportional to the number of aircraft.

In the final column of Table 2, No Flyaway Cost, we exclude flyaway cost as an explanatory variable. All of the variables that were statistically insignificant in the All Variables column are now statistically significant. While the R^2 of this last regression is quite a bit lower than the previous two relationships, the aircraft type and the MDS IOC year variables can stand on their own provided flyaway cost does not mask their importance. Both fighter-attack and cargo aircraft are significantly more expensive than the average of "other" aircraft. Furthermore, each one year increase in the MDS IOC year increases O&S cost per aircraft by about 1.6 percent.

In view of the results obtained in Table 2, the particular structure of the total O&S cost per aircraft cost estimating relationship that is illuminating is depicted in Fig. 10. The O&S cost model can be pictured two different ways. First, O&S costs per aircraft directly relate to average flying hours, the number of aircraft, flyaway cost, and the MD fleet age. This is the Flyaway Only regression of Table 2, and is shown in Fig. 10 by O&S costs per aircraft and the four variables to the left of this dependent variable.

Flyaway cost is, itself, a legitimate proxy for the type of aircraft, be it fighter-attack or cargo, and for the MDS IOC year. As a result, we can also view O&S cost per aircraft as dependent on flying hours, number of aircraft, aircraft type, MDS IOC year, and the MD fleet age. This is the No Flyaway Variable regression of Table 2. As shown in Fig. 10, we have demonstrated that the type of aircraft and MDS IOC year can be viewed as affecting O&S cost per aircraft indirectly through their effect on flyaway cost, the proxy variable.

However, because the R^2 of the No Flyaway Variable regression is much lower than the Flyaway Only regression, flyaway cost can be viewed as not only proxying for aircraft type and MDS IOC year, but also for explaining much more of the variation in O&S cost per aircraft than these variables taken by themselves. The Flyaway Only regression, therefore, has greater explanatory power than the No Flyaway Variable regression.

Several O&S dependent variables are employed in the analysis. We begin with the total O&S and proceed to depot maintenance by sequentially removing cost categories. First we remove P&A to obtain a dependent variable called non-P&A O&S

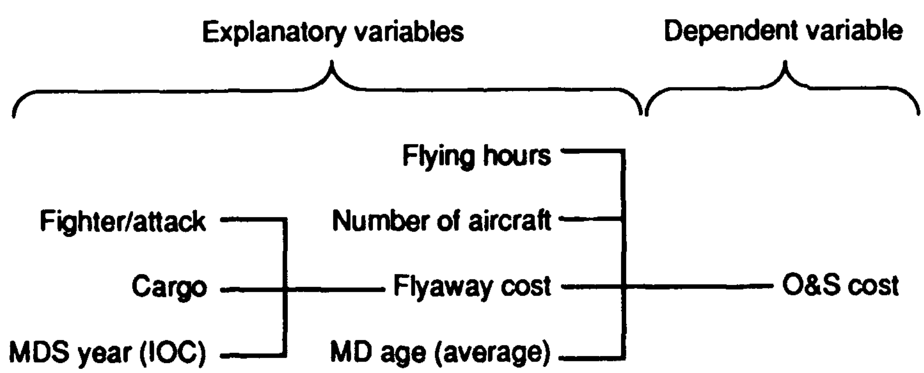

Fig. 10—Structure of cost estimating relationships

cost per aircraft. Table 3 contains the regression results obtained when this variable is related to the same explanatory variables of Table 2.

Unlike the results shown in Table 2, when all variables are included in the regression, the fighter-attack categorical variable is now statistically significant in the comparable regression. This indicates that flyaway cost is not a full proxy for the fighter-attack variable. However, the coefficient of the fighter-attack variable is fairly small. A value of about .13 indicates that, given flyaway cost (and the other variables), knowledge that an aircraft is a fighter-attack increases its predicted cost by about 13 percent. Because P&A costs have been eliminated, this suggests that the personnel cost of fighter-attack aircraft may (other things equal) be somewhat less than the personnel costs of the other aircraft categories.

Table 3

REGRESSION OF NON-PAY AND ALLOWANCE O&S COSTS
(t-statistics in parentheses)

Dependent Variable:
Log of Non-P&A O&S Cost per Aircraft

Independent Variable	All Variables	Flyaway Only	No Flyaway Variable
Log average flying hr	.6697 (16.674)	.5842 (18.785)	.7044 (9.972)
Log number of aircraft	−.0146 (−1.347)	−.0062 (−0.634)	−.0302 (−1.581)
Log flyaway cost	.4457 (28.721)	.4437	— (29.960)
Fighter-attack	.1321 (2.269)	—	.3276 (3.217)
Cargo	−.0683 (−1.183)	—	.2310 (2.312)
MDS IOC year (1944 = 1)	−.0004 (−0.146)	—	.0225 (3.934)
MD fleet average age	.0193 (4.541)	.0134 (5.515)	.0345 (4.638)
Intercept	−5.149 (18.210)	−4.545 (−22.723)	−5.0 (10.224)
Adjusted R_2	.82	.81	.43
No. Observations	400	400	400

If we proceed to the Flyaway Only column, we see that eliminating aircraft type and MDS IOC year only reduces the R^2 by only one percentage point. Also, the coefficient of flyaway cost does not change very much. The coefficient of average flying hours does change, but by less than 10 percent. These factors, plus the small size of the fighter-attack coefficient in the All Variables regression suggests that at the non-P&A level of O&S cost aggregation, it is still reasonable to view flyaway cost as a proxy variable.

We can also see from this column that the coefficient of flying hours per aircraft is somewhat smaller and the coefficient of flyaway cost is somewhat larger than is the case in the Total O&S cost regression. This implies that personnel costs are somewhat more responsive to aircraft flying hours and somewhat less responsive to flyaway cost than the other O&S categories.

Next, we eliminate fuel from the O&S costs to obtain non-P&A, non-fuel O&S costs. The results are reported in Table 4. In the All Variables regression, cargo aircraft is now statistically negatively significant when the costs of fuel are removed, perhaps because these aircraft tend to have high costs in this area. The coefficient is only of moderate size, however, and very little additional variation is explained by including the aircraft type and MDS IOC year variables. Also, the coefficient of the flyaway cost variable changes very little, and the coefficient of the flying hours variable changes by less than 20 percent. It remains reasonable, therefore, to view flyaway cost as a proxy for these variables. The Flyaway Only regression has a great deal of predictive power.

We now eliminate the Other O&S categories to obtain depot maintenance costs per aircraft, and report the regression results in Table 5.

At this level of disaggregation, the justification for using flyaway cost as a proxy for aircraft type and MDS IOC year is more ambiguous. While only a small amount of additional variation in depot maintenance costs is explained by the type and IOC year variables, the coefficient of the statistically significant fighter-attack variable is large. After controlling for the effect of flyaway cost and the other variables, knowledge that an aircraft is fighter-attack increases the predicted depot maintenance cost by about 45 percent. This phenomenon may result from the high level of technology that is embodied in the avionics of fighter-attack aircraft. It may also reflect the extensive wear and tear experienced by the engines. Further analysis, however, is needed of this issue.

Table 4

REGRESSION OF NON-P&A, NON-FUEL O&S COSTS
(t-statistics in parentheses)

Dependent Variable:
Log of Non-P&A, Non-Fuel O&S Cost per Aircraft

Independent Variable	All Variables	Flyaway Only	No Flyaway Variable
Log average flying hr	.5520 (11.576)	.4502 (12.151)	.5837 (8.187)
Log number of aircraft	−.0270 (−2.084)	−.012 (−1.055)	−.0412 (−2.132)
Log flyaway cost	.4062 (22.009)	.4006 (22.706)	—
Fighter-attack	.0997 (1.439)	—	.2778 (2.703)
Cargo	−.1539 (−2.242)	—	.1189 (1.179)
MDS IOC year (1944 = 1)	.0006 (0.154)	—	.0215 (3.735)
MD fleet average age	.0133 (2.637)	.0055 (1.898)	.0271 (3.620)
Intercept	−4.55 (−13.556)	−3.859 (−16.195)	−4.503 (−8.965)
Adjusted R_2	.70	.69	.32
No. Observations	400	400	400

Also, note from the Flyaway Only regression of Table 5 how O&S costs are more responsive to flying hours when aircraft type and MDS IOC year are included. Apparently, when these variables are excluded from the Flyaway Only regression, the coefficient of the flying hours variable embodies the fact that the low flying hour, fighter-attack variables have fairly high O&S costs, thereby reducing the size of the regression coefficient.

In spite of this, the coefficient of flyaway cost remains quite stable when additional variables are included. The coefficient of this variable in Table 5 has increased markedly from its size in Table 1. There is also some tendency for the responsiveness of O&S cost to flying hours to decrease when moving from Table 2 to the Flyaway Only column of Table 5.

Table 5

REGRESSION OF DEPOT MAINTENANCE COSTS
(t-statistics in parentheses)

Dependent Variable: Log of Depot Maintenance Cost per Aircraft			
Independent Variable	All Variables	Flyaway Only	No Flyaway Variable
Log average flying hr	.5139 (7.074)	.3285 (5.749)	.5727 (4.688)
Log number of aircraft	−.0046 (−0.234)	−.0021 (−0.118)	−.0309 (−0.935)
Log flyaway cost	.7535 (26.841)	.7684 (28.236)	—
Fighter-attack	.4553 (4.321)	—	.7857 (4.462)
Cargo	.0143 (0.138)	—	.5204 (3.011)
MDS IOC year (1944 = 1)	.0052 (0.873)	—	.0442 (4.463)
MD fleet age	.0259 (3.364)	.0056 (1.250)	.0515 (4.007)
Intercept	−7.079 (−13.840)	−5.357 (−14.572)	−6.974 (−8.104)
Adjusted R_2	.72	.71	.22
No Observations	400	400	400

Such a result is not surprising when one acknowledges that depot maintenance is a type of remanufacturing. As a result, one might expect the costs to be more responsive to flyaway cost than to flying hours. Because depot maintenance costs do not increase proportionally with flyaway costs, high cost aircraft may have reliability and maintainability enhancements embodied in them that tend to reduce depot maintenance costs from what they would have been without these enhancements. At the same time, we can see from the regression that excludes flyaway cost that depot maintenance costs are increasing with the MDS IOC year faster than in the case of more aggregated regressions. This, however, can be directly traced to the large coefficient of the flyaway cost variable.

It might be helpful to summarize some of the findings from our empirical analysis. Total operating and support costs are very responsive to changes in flying hours; depot maintenance costs less so. Depot maintenance costs are, however, very responsive to flyaway cost; total operating and support costs less so. Apparently P&A and fuel costs are strongly affected by flying hours; depot maintenance by the remanufacturing process. Although the depot maintenance responsiveness to flyaway cost is high, it is a less than proportional response. High (flyaway) cost aircraft may contain reliability and maintainability enhancements that attenuate the depot costs.

While we have not found evidence for the downward sloping portion of the bathtub curve (see also the appendix), we do show that O&S cost per aircraft increases with the age of the mission design fleet. Other things equal, a one year increase in the average age increases total O&S costs per aircraft by about 1.7 percent; the response also remains positive at the lower cost aggregation levels.[6]

We also show that O&S costs are responsive to MDS IOC year. A one year increase in IOC increases total O&S costs per aircraft by about 1.6 percent. Recently deployed aircraft are more expensive to operate than earlier generation aircraft. But this effect seems to be driven primarily by the higher flyaway costs of the recent aircraft.

[6]The Air Force Cost Center employs a bathtub curve to estimate the AFR 173-13 planning factors for depot maintenance. Using WSCRS data, which also feeds into VAMOSC but which are available over a more extensive time period, they have found rough evidence of a bathtub curve being applicable. The specific planning factors for MD aircraft are identified through the appropriate vertical displacement of this generic curve. The depot maintenance planning factors of WSCRS are related to numbers of PAA and flying hours by assuming that 100 percent of WSCRS airframe maintenance costs are associated with PAA, 100 percent of the engine costs are associated with flying hours, and 65 percent of the avionics costs are associated with flying hours and 35 percent with PAA.

IV. CONCLUSIONS AND RECOMMENDATIONS

We have shown that many of definitional issues limit comparisons between VAMOSC and other data bases. For example, the broader AFR 173-13 and F&FP coverage of sustaining investment creates some inconsistencies. Further analysis of these definitional issues is merited.

The cost-estimating model demonstrates the importance of flyaway cost and flying hours in explaining variations in the O&S cost of our VAMOSC sample. Its value as a predictive relationship remains to be seen in our planned analysis of VAMOSC data for subsequent years. Compared with the very steep upward sloping portion of the bathtub curve described in Fig. 9, however, we find only a moderate effect of mission design age on O&S costs. Perhaps the effect of MDS IOC year on O&S cost might be described as moderate as well.

As long as a sharp separation remains in the F&FP between those resources programmed directly for the forces and those programmed for indirect support, it will be very difficult to evaluate how changes in service budgets affect military readiness. Clearly, DoD needs to better understand the readiness implications of the service budget displays. A closer connection between the budget displays and historical cost accounting systems would aid this process. Allocation rules are needed for the budget displays similar to those that have been developed for VAMOSC.

Finally, we believe that our estimated relationships can play a useful role in approximating O&S cost for the USAF aircraft total. These relationships may also be relevant early in the acquisition process for estimating the O&S costs of a particular aircraft. Later in the process, of course, as detailed information about basing and maintenance concepts are more fully known, detailed "bottom-up" methods of analysis would be preferable. Eventually, one may hope for full consistency between the "top-down" methods of this analysis and the more detailed weapons-specific O&S cost analyses.

Appendix

DATA AND REGRESSION ANALYSIS OF VAMOSC

INTRODUCTION

Many data and statistical analysis issues inevitably must be addressed when developing a cost estimating relationship. In this appendix, we discuss several major issues that emerged during our analysis.

We first discuss the identification and elimination of certain VAMOSC aircraft observations in the data base. These include obsolete aircraft, those for which flyaway cost data are not available, and aircraft maintained using "full service contracts." We also discuss our removal from VAMOSC of the costs associated wi·h the acquisition of modification kits, and describe the sources used to identify the IOC year of an aircraft MDS and the average MD fleet age.

To investigate whether the cost model is stable over time, we have analyzed the data from both a cross sectional and time series standpoint. We also briefly discuss the presence of a bathtub-shaped cost curve of the type depicted in Fig. 8. There is also a discussion of the effect of substituting PAI data for comparable data in VAMOSC.

Finally, there is a detailed analysis of the cost-allocation issue. We show that, although a considerable portion of O&S costs are allocated to aircraft MDS using specified rules, this does not seem to affect the broad character of our empirical results. The allocation rules yield a reasonable estimate of the marginal cost of the relevant activity.

SCREENING VAMOSC DATA

Selection of Relevant Aircraft

VAMOSC contains all aircraft possessed by the Air Force commands. Even when an aircraft is being phased out of active service, however, it may temporarily remain in VAMOSC as the aircraft is used for ground training purposes or awaits its final disposition. For such an aircraft, some minor personnel costs may be incurred. There would not be any costs incurred, however, for other O&S categories such as POL and depot level maintenance. To identify obsolete aircraft in the VAMOSC data base, we

applied the following rule: When no flying hours or fuel usage are identified, the aircraft is considered obsolete. Table A.1 shows the list of these obsolete aircraft.

In our analysis, obsolete aircraft are removed in the year they become obsolete. It so happened, however, that no previous data existed for these aircraft, except in the case of the B52D. The B52D was phased out of the inventory in 1985, and 1984 might be considered a transitional year. We examined the effect of including the 1984 data for this aircraft and found that including the 1984 data for B52D did not have a marked effect on the overall regression results. The 1984 data, however, was retained, and the B-52D was eliminated from the data base in 1985.

There is a similar issue when aircraft are first introduced into the inventory. For these aircraft, some O&S costs might not occur at the normal level. A recent example of new aircraft is the B1B, which first appeared in VAMOSC in 1986. When we removed this aircraft from the data base, however, we obtained results very similar to that reported in Table 2.[1]

The flyaway cost information used in this study was obtained from AF Regulation 173-13. However, for some selected aircraft MDS, this information was not available. To estimate the cost estimating relationship, it was necessary to eliminate these aircraft from the data base. The aircraft for which flyaway cost data were not available are contained in Table A.2.

Table A.1

OBSOLETE AIRCRAFT IN VAMOSC

MDS	Year of Obsolescence	No. Aircraft
B052D	1985	14.32
T041A	1984	8.02
QF100D	1983	6.51
QF100F	1985	1.95
QF102A	1981	4.29
YQF100D	1984	1.17

[1]When the 1986 B1B data and the 1984 B52D data were removed from the data base, the following regression results were obtained:

$$\text{Log ave. O\&S} = \underset{(-20.9)}{-4.16} + \underset{(21.1)}{.66}\text{Log ave. flying hours} - \underset{(-3.4)}{.031}\text{Log no.aircraft}$$

$$+ \underset{(27.4)}{.38}\text{Log flyaway cost} + \underset{(7.7)}{.02}\text{ fleet age}$$

VAMOSC Data Limitations

There have been several of refinements to VAMOSC since 1981, the first year in which data were collected. For example, there is now a more detailed set of cost categories. Typically, however, previous year data were not revised based on these refinements. In the next several sections, we discuss some of data limitations encountered in our analysis and the steps taken to deal with them.

Maintenance Service Contracts

For several of the aircraft in the VAMOSC data base, many of the depot level maintenance activities are performed by contractors. For example, in 1986, the data base indicated that the total costs for depot level maintenance was $2.07 billion. Of this amount, $475 million was reported for "contract services." However, outside service contract costs are not always reported.

There are two situations in which service contracts might not be reported. The first is when there is no information in VAMOSC on several aircraft that rely substantially or totally on commercial contractors for depot level maintenance. The second occurs when an aircraft is leased from a commercial source, and depot level maintenance might be part of the leasing agreement. If this is the case, these costs would not be reported separately as depot maintenance expenditures.

Table A.2

AIRCRAFT WITH MISSING FLYAWAY COST DATA

MDS	No. Aircraft
C021A	44.51
F101B	11.49
F101F	6.2
F104G	9.26
QF100D	34.22
QF100F	2.36
QF102A	1.53
TF104G	6.2
TR001A	13.61
TR001B	2.16
UV018B	1.95
YQF100D	1.17

Ideally, to make the depot maintenance costs comparable across aircraft and over time, all the costs associated with the commercial contracts should be added to the VAMOSC data. Unfortunately, the necessary information on the full service contract aircraft is not readily available from other sources. Therefore, these aircraft were deleted from the VAMOSC data base. Table A.3 contains the VAMOSC aircraft MDS that relied on full service contracts.

Modification Kit Acquisition and Installation

In terms of the reporting format specified by the CAIG, a clear distinction is made between the Class IV modification installation costs and acquisition costs. Modification installation is considered part of depot level maintenance, while the acquisition of the kits themselves is part of sustaining investment.

Table A.3

FULL SERVICE CONTRACT AIRCRAFT

MDS	Year Under Contract	No. Aircraft in Latest Year
A037B	1982	1.27
C009A	1981–86	17.14
C009C	1981–86	2.36
C012A	1981–86	1.83
C012F	1984–86	26.44
C020A	1984–86	2.75
C021A	1984–86	44.51
C023A	1985–86	13.31
E004B	1983–86	3.26
F104G	1981–83	9.26
T041A	1985–86	50.25
T041C	1981–82	49.86
T043A	1981–86	15.62
AT038B	1981–86	108.55
CT039A	1986	1.05
EC130H	1982–83	6.44
KC010A	1982–86	40.46
MH053H	1986	2.01
TF104G	1981–83	6.2
TR001A	1982–86	3.16
UH060A	1983	2.16
UV018B	1981–82	1.95

SOURCE: Hq. AFLC/LMSC/SMPE.

The reporting of the acquisition costs of Class IV modification kits has only recently become complete. As shown in Table A.4, before 1985 costs were reported only on a handful of MDS aircraft. Furthermore, the reliability of the data is uncertain. For example, in both 1983 and 1984, although there were no appreciable changes in the number of MDSs reporting, the aggregate modification kit procurement costs increased dramatically.

A more systematic collection and reporting of this cost category occurred in 1985 when the Class IV modification kit procurement information in the WSCRS data base was introduced into VAMOSC, reflected in the increase in the number of reporting aircraft. Table A.4 also shows that in 1986, more cost data were reported, thereby substantially increasing the aggregate cost in that year. In percentage terms, the 1986 Class IV modification kit acquisition costs were 40 percent of sustaining investment and 2.3 percent of total O&S costs. By comparison, in 1985 the reported costs were 33 percent and 1.5 percent, respectively, of the total.

As this new data collection effort continues, the time series on modification kits will become correspondingly more reliable and more useful for analysis. Because of the historical limitations, however, we decided to exclude this category from the analysis.

Until 1986, Class IV modification kit installation costs were included in the VAMOSC aggregate depot level maintenance costs. In 1986, VAMOSC began to report this item separately. Since it was not possible to disaggregate the earlier depot level cost data, we decided to incorporate the 1986 modification installation cost data into the depot maintenance category.

Table A.4

REPORTING OF MODIFICATION KIT ACQUISITION COSTS
(Million 1986$)

	No. MDS Reported Mod. Cost		
Year	No Cost Data	Some Cost Data	Cost Reported
1981	86	6	$28.6
1982	86	8	32.2
1983	83	7	160.3
1984	86	7	272.5
1985	30	68	237.3
1986	25	78	351.6

Incidentally, no data were reported for interim contract support or contractor logistics support for the 1981–1985 period. Data were reported for this category in 1986. Our investigation indicated that these data were not incorporated in VAMOSC during the early years. To make the data series comparable over time, these two cost items were subtracted from the total O&S costs in 1986.

IOC Year and Average Age of MD Fleet

Because of the fragmentary nature of the information, we collected the data on MDS IOC year from a variety of sources. These sources are listed in the footnote of Table A.5, which is a composite list by MDS aircraft. The table also shows the average age of each MDS fleet in 1986.

Technically, the IOC year denotes a specific year, but information is not always available to strictly apply this definition. Instead, a broader criterion was used, because some sort of "milestone" or "first" is always observed. Examples include the first test flight, the first year of production, or the first year of delivery. When all sources were exhausted for a particular MDS designated aircraft, the IOC year of the closest member of the same aircraft MD was used.

In compiling the information on the age of MD fleet, we relied heavily on the Air Force Almanac, published in the *Air Force Magazine*. However, the information was available primarily at the basic mission and design level (such as C130, instead of C130E and C130H). Nevertheless, the VAMOSC data base contains a large number of aircraft MDs and this information is quite useful in the empirical analysis.

REGRESSION ANALYSIS

In this section, we will discuss some of the issues encountered in our regression analysis. These include the use of flyaway cost as a proxy variable, the pooling of cross section and time series data, the empirical support for the "bathtub" cost curve, and the effect of substituting PAI data for the VAMOSC possessed aircraft totals.

Flyaway Cost as a Proxy Variable

This Note showed that at the total O&S cost level of aggregation, flyaway cost serves as a useful proxy for aircraft type and the level of technology reflected in the MDS IOC year. Such a phenomenon can be expected if costs are optimally allocated to modernization and readiness—that is, at the margin to flyaway costs and O&S costs.

In a simple model in which a budget is allocated to two broad aircraft categories, one would strive to obtain the same rate of substitution between flyaway and operating and support costs between the two categories. Furthermore, if changes in the level of technology affect both aircraft production and operations symmetrically, this relationship may remain stable over time. It is reasonable to hypothesize that flyaway cost is a proxy for both aircraft type and the MDS IOC year. This hypothesis is based on a simplified view of decisionmaking and needs to be carefully explored with data. Therefore, we have expanded the analysis of this topic by considering more disaggregated categories of aircraft

A set of two aircraft mission-category variables, fighter-attack and cargo, were employed in Table 2. These two aircraft groups represent the bulk of observations in the data set, with the fighter-attack group showing 38 percent and the cargo group showing 48 percent. At this total O&S cost aggregation level, only when the flyaway cost variable is removed do the coefficients of the aircraft group variables and the IOC year become statistically significant. The implication is that flyaway cost is a reasonable proxy for aircraft type and MDS IOC year at the regression model's level of aggregation.

We also concluded in the text that at lower levels of O&S cost aggregation, aircraft categorical variables could be statistically significant in a regression that included flyaway cost. For example, in regressions in which non-P&A O&S costs or depot maintenance costs are the dependent variable, the fighter-attack variable is statistically significant; in the regression in which non-P&A, non-fuel is the dependent variable, the cargo variable is statistically significant. Yet, although these variables are significant, the R^2 does not increase significantly from that obtained in the regression that excludes these variables. This implies that the model that uses flyaway cost as a proxy for aircraft category and IOC year has as much explanatory power as the model that includes the aircraft categories and the MDS IOC year.

To pursue this issue further, we have divided each broad fighter-attack versus cargo mission groups into more detailed mission design groups. The fighter-attack group was divided into fighter and attack aircraft and cargo aircraft into modified and nonmodified designs. In terms of the composition in the data set, the split between fighter and attack is six to one; the split between modified and nonmodified cargo is three

Table A.5

MDS IOC YEAR AND MD AVERAGE FLEET AGE

MDS	IOC Year (1944 = 1)	Fleet Age (in 1986)	IOC Year MDS	Fleet Age (1944 = 1)	(in 1986)
A007D	25	14.9	F111F	27	15.4
A007K	25	14.9	O002A	23	17.2
A010A	32	5.9	T033A	1	28.6
B001B	42	1.2	T037B	16	24.3
B052D	12	24.0[a]	T038A	13	20.5
B052G	14	26.0	AC130H	32	18.6
B052H	17	26.0	EC130E	19	18.6
C005A	25	13.6	EC130H	32	18.6
C005B	42	13.6	EC135A	17	25.2
C130E	19	18.6	EC135C	21	25.2
C130H	32	18.6	EC135G	21	25.2
C135B	19	25.2	EC135H	21	25.2
C135C	21	25.2	EC135J	21	25.2
C137B	22	17.3	EC135K	21	25.2
C137C	22	17.3	EC135L	21	25.2
C141B	36	20.0	EC135P	21	25.2
E003A	34	6.9	EF111A	38	15.4
E003B	41	6.9	FB111A	24	15.9
E003C	41	6.9	HC130H	20	18.6
F004D	21	16.4	HC130N	26	18.6
F004E	23	16.4	HC130P	26	18.6
F004G	35	16.4	KC135A	13	25.2
F005B	31	10.7	KC135D	21	25.2
F005E	29	10.7	KC135E	21	25.2
F005F	29	10.7	KC135Q	21	25.2
F015A	30	6.5	KC135R	39	25.2
F015B	30	6.5	MC130E	19	18.6
F015C	36	6.5	OA037B	24	13.2
F015D	36	6.5	OV010A	24	17.9
F016A	35	3.3	RC135S	21	25.2
F016B	35	3.3	RC135U	21	25.2
F016C	42	3.3	RC135V	21	25.2
F016D	42	3.3	RC135W	21	25.2
F106A	13	26.7	RF004C	21	16.4
F106B	14	26.7	WC130E	19	18.6
F111A	22	15.4	WC130H	32	18.6
F111D	25	15.4	WC135B	19	25.2
F111E	24	15.4			

Table A.5—continued

SOURCES: *The Great Book of Modern Warplanes,* Portland House, New York, 1987. *TACAIR Performance/Cost Analysis: Trends over Time,* The Analytic Sciences Corporation, 1981

U.S. Military Aircraft Cost Handbook, Management Consulting & Research, Inc., 1983.

The Rand McNally Encyclopedia of Military Aircraft, The Military Press, New York, 1980.

R. W. Hess and H. P. Romanoff, *Aircraft Airframe Cost Estimating Relationships, Study Approach and Conclusions,"* The RAND Corporation, R-3255-AF, December 1987.

M.B. Rothman, *Aerospace Weapon System Acquisition Milestones: A Data Book,* The RAND Corporation, N-2599-ACQ, October 1987.

U.S Air Force Almanac, Air Force Magazine, May issues, various years.

[a]Fleet age for B52D is for 1984.

to one. The regression results when total O&S costs per aircraft is the dependent variable are presented in Table A.6.

Table A.6 is similar in organization to Table 2. The aircraft categorical variables and the IOC year variable are significant only when the flyaway cost variable is removed from the regression. This provides further support for using flyaway costs as a proxy for aircraft type and IOC year at the highest level of O&S cost aggregation.

Regressions at Lower Levels of O&S Cost Aggregation

To parallel the approach taken in the text, we determined whether this same phenomenon is present at lower levels of O&S cost aggregation. As before, we consider the following cost categories: (1) non-P&A O&S, (2) non-P&A, non-fuel O&S, and (3) depot maintenance. These results are shown in Tables A.7–A.9, which parallel Tables 3 through 5. Similar to the findings reported in the text, we discover that the role of flyaway cost as a proxy for aircraft type is affected somewhat by idiosyncratic factors at lower cost levels.

In the regression that also includes flyaway cost, the non-P&A O&S costs of fighters are significantly positive, whereas the modified cargo aircraft are negative. In contrast, as shown in Table A.6, neither of these variables had significant coefficients in the total O&S cost regression. This suggests that fighters may be less labor-intensive and modified cargo more labor-intensive than one would predict from their flyaway cost. Modified cargo aircraft also remain statistically significant when fuel costs are removed. Fighters, however, are not statistically significant at this non-P&A, non-fuel cost aggregation (Table A.8), perhaps reflecting that fighters are used less intensively than cargo aircraft.

Table A.6

EFFECTS OF AIRCRAFT TYPE AND IOC YEAR ON TOTAL O&S COSTS
(t-statistics in parentheses)

Dependent Variable:
Log Total O&S Cost per Aircraft

Independent Variable	All Variables	Flyaway Only	No Flyaway Variable
Log average flying hr	.6119 (15.170)	.6142 (20.353)	.6524 (10.010)
Log number of aircraft	–.0479 (–4.295)	–.0381 (–3.996)	–.0743 (–4.139)
Log flyaway cost	.3930 (25.150)	.3918 (27.269)	—
Fighter	.0061 (0.113)	—	.2415 (2.583)
Attack	–.0660 (–0.811)	—	–.2392 (–1.824)
Modified cargo	–.0313 (–0.537)	—	.2015 (2.159)
Non modified cargo	.0664 (0.961)	—	.3533 (3.202)
MDS IOC year (1944 = 1)	–.0047 (–1.447)	—	.0128 (2.473)
MD fleet age	.0130 (3.126)	.0171 (7.224)	.0238 (3.533)
Intercept	–3.6265 (–12.725)	–3.8540 (–19.853)	–3.4774 (–7.547)
Adjusted R^2	.82	.82	.54
No. Observations	400	400	400

When we examine depot maintenance costs alone (Table A.9), both fighters and modified cargo aircraft are more expensive than one would expect based on their flyaway cost. This may be accounted for by the fighters' high level of technologically driven depot maintenance requirements and the effect of using nonmodified cargo aircraft so intensively.

Therefore, the role of flyaway cost as a proxy for aircraft type and IOC year is most unambiguous at the total O&S cost level. As would be expected, when one looks at more detailed levels of cost, factors specific to aircraft types become more important.

Table A.7

EFFECTS OF AIRCRAFT TYPE AND IOC YEAR ON NON-P&A O&S COSTS
(t-statistics in parentheses)

Dependent Variable: Log Non-P&A Costs O&S per Aircraft			
Independent Variable	All Variables	Flyaway Only	No Flyaway Variable
Log average flying hr	.6423 (15.868)	.5842 (18.785)	.6876 (9.807)
Log number of aircraft	−.0270 (−2.410)	−.0062 (−0.634)	−.0565 (−2.925)
Log flyaway cost	.4393 (28.019)	.4437 (29.960)	—
Fighter	.1374 (2.339)	—	.4001 (3.977)
Attack	.0480 (0.588)	—	−.1456 (−1.032)
Modified Cargo	−.1252 (−2.135)	—	.1351 (1.345)
Non modified cargo	.0827 (1.193)	—	.4034 (3.399)
MDS IOC year (1944 = 1)	−.0014 (−0.437)	—	.0182 (3.264)
MD fleet age	.0189 (4.519)	.0134 (5.515)	.0309 (4.272)
Intercept	−4.889 (−17.097)	−4.5458 (22.723)	−4.722 (−9.528)
Adjusted R^2	.82	.81	.47
No. Observations	400	400	400

From Tables A.6 and A.7–A.9, the R^2 of the regression with all variables present is only slightly higher than for the regression in which the aircraft type and IOC year are excluded. This indicates that the predictive power of a regression that contains flyaway cost as a proxy for aircraft type and IOC year is virtually as strong as one that includes all variables. Therefore, in spite of certain idiosyncratic factors at lower cost levels of aggregation, the use of flyaway cost as a proxy, which is statistically justified at the total cost level, remains relevant at the lower cost levels.

Pooling of Cross-Sectional and Time Series Data

Our study analyzed the VAMOSC data base between 1981 and 1986. Even though some MDSs became obsolete during this period, the number of observations were roughly the same each year, as shown in Table A.10.

To see if the cost effects changed over time, we ran separate regressions on each year's data. While the results presented in Table A.11 showed some differences, overall they were fairly small. There are, however, two noticeable deviations. One is the effect

Table A.8

EFFECTS OF AIRCRAFT TYPE AND IOC YEAR ON NON-P&A, NON-FUEL O&S COSTS
(t-statistics in parentheses)

Dependent Variable:
Log Non-P&A, Non-fuel O&S Costs per Aircraft

Independent Variable	All Variables	Flyaway Only	No Flyaway Variable
Log average flying hr	.5216 (10.801)	.4502 (12.151)	.5628 (7.928)
Log number of aircraft	−.040 (−3.022)	−.0123 (−1.055)	−.0672 (−3.436)
Log flyaway cost	.3995 (21.358)	.4006 (22.706)	—
Fighter	.1043 (1.488)	—	.3432 (3.369)
Attack	.0126 (0.130)	—	−.1634 (−1.144)
Modified cargo	−.2165 (−3.093)	—	.0202 (0.199)
Non modified cargo	.0123 (0.149)	—	.3040 (2.530)
MDS IOC year (1944 = 1)	−.0004 (−0.105)	—	.0175 (3.091)
MD fleet age	.0130 (2.594)	.0055 (1.898)	.0239 (3.256)
Intercept	−4.2741 (−12.526)	−3.8598 (−16.195)	−4.1225 (−8.215)
Adjusted R^2	.70	.69	.36
No. Observations	400	400	400

of flying hours in the 1984 regression and the other is the effect of the average MD fleet age in the 1986 regression. In both cases, the coefficients are smaller.

The intertemporal difference hypothesis was formally tested by using category variables for each different year. This use of the year dummy variables and their interaction terms in a pooled regression showed (in Table A.12) no discernible differences between years.

Bathtub-Shaped Cost Curve

Some analysts believe that as an aircraft model goes through the maturation cycle, the O&S costs are expected to resemble a bathtub curve as the weapons age. In the initial phase of the service life of the aircraft, the O&S costs decline as learning takes place and there is a gradual reduction in the changes in replenishment spares stockage. This early phase is followed by a mid-life steady state in which the O&S costs remain stable for several years. Eventually, however, O&S costs rise as the aircraft model ages.

We found no strong evidence to support the bathtub hypothesis. The effect was modeled using a time-squared variable. In this case, we squared the IOC years of an MDS, and we tested whether there evidence of any shift from a downward to an upward sloping pattern. We were not able to find any evidence of a downward sloping pattern during an aircraft's early operational years.[2]

USAF PAI Data

The PAI aircraft of a unit equals the number of aircraft assigned to the units to meet the operational missions. Associated with the PAI data are flying hour data. If an aircraft is sent to the depot for maintenance, or if it is deployed from an Air Force command to a unified or specialized command, it would not be "possessed" by the Air Force command. Although one would expect the VAMOSC data for possessed aircraft to closely follow the PAI data, the total aircraft owned by the command are based on a

[2]Using WSCRS data, the Air Force Cost Center has found some evidence of a downward sloping portion of the cost curve for depot maintenance during the early years of service life for broad mission-level classes of aircraft. Information from WSCRS is available from the mid-seventies, however, while the VAMOSC data begins in 1981. To test the bathtub curve hypothesis for depot maintenance using a more extensive data set, a cost estimating relationship could be developed using WSCRS data. In addition, the downward sloping portion of the bathtub curve can arise, in part, from gradual reductions in the replenishment spares stockage changes. This phenomenon would not be captured in VAMOSC, which contains only replenishment spares condemnations.

Table A.9

EFFECTS OF AIRCRAFT TYPE AND IOC YEAR ON DEPOT COSTS
(t-statistics in parentheses)

Dependent Variable:
Log Depot Costs per Aircraft

Independent Variable	All Variables	Flyaway Only	No Flyaway Variable
Log average flying hr	.4792 (6.562)	.3285 (5.749)	.5548 (4.613)
Log number of aircraft	-.0295 (−1.461)	−.0021 (−0.118)	−.0788 (−2.378)
Log flyaway cost	.7335 (25.928)	.7684 (28.236)	—
Fighter	.4991 (4.706)	—	.9376 (5.433)
Attack	.1629 (1.105)	—	−.1603 (−0.662)
Modified cargo	−.0782 (−0.739)	—	.3566 (2.070)
Non modified cargo	.2561 (2.045)	—	.7915 (3.887)
MDS IOC year (1944 = 1)	.0031 (0.520)	— (3.751)	.0360
MD fleet age	.0244 (3.222)	.0056 (1.250)	.0444 (3.573)
Intercept	−6.6467 (−12.881)	−5.3573 (−14.572)	−6.3684 (−7.489)
Adjusted R^2	.73	.71	.28
No. Observations	400	400	400

different counting rule. VAMOSC counts the aircraft only for the period of time that the command actually possesses the aircraft.

The relationship between PAI and possessed aircraft was explored using the 1986 data for both numbers of aircraft and flying hours. Figure A.1 plots the number of aircraft in VAMOSC on the vertical axis and the PAI total on the horizontal axis. Figure A.2 plots the number of flying hours in the two data bases. These two figures visually show a clear relationship between PAI data and VAMOSC data. Their coefficients of correlation were close to 1.0. Table A.13 shows the regression results obtained by using

Table A.10

DISTRIBUTION OF MDS BY YEAR

Year	No. Observations	Percent
1981	62	15.50
1982	63	15.75
1983	64	16.00
1984	67	16.75
1985	70	17.50
1986	74	18.50
Total	400	100.00

the substituted 1986 PAI data. All coefficients stayed virtually unchanged. The t-statistics for the 1986 dummy variables are very low.[3]

Cost Allocation

As we have indicated, not all VAMOSC costs are directly collected at the MDS level. Less than 50 percent of the VAMOSC costs are allocated to aircraft MDS using decision rules that attempt to identify the marginal cost of a particular activity. These calculations are typically made by allocating these costs to aircraft MDS using flying hours and possessed aircraft.

In this section, we provide evidence that the allocation rules yield a reasonable estimate of the cost of an activity. The aircraft MDS cost totals therefore constitute a legitimate dependent variable for the empirical analysis.

To address the allocation issue, we first briefly describe the rules that are used to associate costs with aircraft MDS. Then we present several cost estimating relationships in which the dependent variables are the part of those O&S categories for which data are collected at the MDS level. Because the bulk of depot maintenance costs are directly collected at the MD level, and the effect of the allocation rules on other O&S costs is likely to be attenuated at this level, we also present the cost estimating relationships that apply at the MD level.

[3]We also smoothed the 1986 VAMOSC data by regressing VAMOSC aircraft and flying hours on their PAI counterparts. Estimates from the smoothed data are similar to those shown in Table A.13.

Table A.11

RESULTS OF REGRESSION BY YEARLY DATA
(t-statistics in parentheses)

Dependent Variable:
Log of Total O&S Cost per Aircraft

Independent Variable	1981	1982	1983	1984	1985	1986
Log average flying hr	.6541 (8.402)	.6314 (7.182)	.6490 (8.432)	.5185 (9.783)	.6993 (8.512)	.6139 (7.060)
Log number of aircraft	−.0274 (−1.204)	−.0351 (−1.417)	−.0330 (−1.487)	−.0578 (−2.539)	−.0190 (−0.817)	−.0515 (−1.986)
Log flyaway costs	.3802 (10.668)	.4289 (11.485)	.3897 (11.981)	.3837 (11.431)	.3579 (10.091)	.3879 (9.957)
Average fleet age	.0166 (2.555)	.0220 (3.286)	.0174 (3.058)	.0169 (2.867)	.0169 (3.012)	.0103 (1.760)
Intercept	−4.161 (−8.962)	−4.1171 (−7.460)	−4.0647 (−8.215)	−3.1546 (−8.403)	−4.3548 (−8.451)	−3.669 −6.353)
Adjusted R^2	0.8411	0.8228	0.8389	0.8317	0.8080	0.7625
No. Observations	62	63	64	67	70	74

Allocation Rules

Our summary of the cost allocation rules will be somewhat simplified to convey the essential ideas. To fully understand the process, the reader is referred to the Air Force documents. We have organized the discussion by the major O&S categories of the VAMOSC WSSC system.[4]

Unit Mission Personnel. The costs associated with aircrews and maintenance personnel are collected at the MDS level. However, Command Staff and Other Unit Personnel costs that are incurred by a command at a particular base (command/base) are allocated to the aircraft MDS using a proportion calculated by giving equal weight to the MDS's shares of command/base flying hours and possessed aircraft. In contrast, for Security Personnel, only the MDS's share of the number of command/base aircraft is used to allocate the command/base costs.

[4]See Sec. II, fn. 7, for a discussion of the documents describing the allocation rules.

Unit Level Consumption. Both POL and Training Ordnance are available at the MDS level. Maintenance Materiel, however, is allocated using the MDS's share of command/base maintenance hours.

Depot Level Maintenance. Aircraft Overhaul cost data is available at the MDS level. This on-equipment depot maintenance category constitutes about 40 percent of VAMOSC depot maintenance costs. It has also been estimated that more than 10 percent of other depot costs are available at the MDS level. About 85 percent of total depot maintenance costs and 99 percent of engine overhaul costs are directly collected at the MD level.

When allocation is necessary, the cost of Engine Overhaul and Accessories is assigned to aircraft MDS using flying hours. In contrast, 35 percent of Avionics, Armament and Aircraft Accessories is assumed to be related to aircraft inventory; 65 percent of the costs are related to flying hours. These percentages are based on the assessment of Air Force analysts.

Sustaining Investments. The cost of both Replenishment Spares and Class IV modification kits are allocated to aircraft MDS using either flying hours or aircraft inventory depending on whether the procurement requirements for the relevant component are determined on the former or the latter basis.[5]

Installation Support Personnel. These costs, including those associated with Real Property Maintenance, Communications, and Base Operating Support are allocated to aircraft MDS at a particular base by first identifying the Installation Support Strength. These support personnel are then allocated to aircraft operations at the installation by multiplying this identified total by the ratio of total relevant aircraft O&M personnel to the total installation population. Then, the resulting portion of installation support personnel is allocated to aircraft MDS using a proportion that is derived by giving equal weight to the MDS's shares of installation flying hours and possessed aircraft.

Indirect Personnel Support. The allocation of Miscellaneous Operations and Maintenance costs is similar to Installation Support Personnel with the exception that the relevant base Miscellaneous O&M costs rather than the installation support strength are first identified.[6]

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[5]Conversations with Roger Steinlage of Hq. AFLC on depot maintenance and sustaining investment have been helpful.

[6]To identify the variable cost of the installation support personnel and the indirect personnel support, one might consider taking account of the fixed cost elements that are part of the base opening package discussed in Sec. II, fn. 2.

Table A.12

POOLED REGRESSION: YEAR DUMMY VARIABLES AND INTERACTION TERMS

Dependent Variable: Log of Total O&S Cost per Aircraft		
Independent Variable	Coeff.	t-stat.
Log average flying hr	.6541	8.043
Log number of aircraft	−.0273	−1.152
Log flyaway cost	.3801	10.213
MD fleet age	.0166	2.446
Year Category:		
1982 = 1	.0437	0.061
1983 = 1	.0961	0.131
1984 = 1	1.0061	1.595
1985 = 1	−.1939	−0.272
1986 = 1	.4911	0.704
Interaction with Log average flying hr		
1982 = 1	−.0227	−0.193
1983 = 1	−.0050	−0.043
1984 = 1	−.1355	−1.365
1985 = 1	.0451	0.388
1986 = 1	−.0401	−0.362
Interaction with Log number of aircraft		
1982 = 1	-.0077	-0.231
1983 = 1	-.0056	-0.166
1984 = 1	-.0305	-0.894
1985 = 1	.0084	0.254
1986 = 1	−.0241	−0.738
Interaction with Log flyaway cost		
1982 = 1	.0487	0.940
1983 = 1	.0095	0.183
1984 = 1	.0035	0.069
1985 = 1	−.0222	−0.430
1986 = 1	.0076	0.152
Interaction with MD fleet age		
1982 = 1	.0054	0.577
1983 = 1	.0008	0.088
1984 = 1	.0003	0.039
1985 = 1	.0002	0.026
1986 = 1	−.0063	−0.743
Intercept	−4.160872	−8.580
Adjusted^2	0.8164	
No. Observations	400	

Medical costs are allocated to aircraft MDS by first identifying the medical costs *directly* associated with total aircraft O&M at a base. These costs are derived by multiplying a specified medical factor by the personnel strength at the base associated with aircraft O&M. The base level O&M strength is, however, itself supported by installation support personnel to which the medical factor is also applied. The total (direct plus indirect) medical costs, so identified, are then allocated to an aircraft MDS using the proportion obtained by giving equal weight to the MDS's share of base flying hours and possessed aircraft.

General Depot Support. This broad category includes supply, inventory control, and procurement operations. At each depot one first allocates these costs to aircraft using aircraft's share of the dollar value of all items managed at the depot. The costs are then allocated to an aircraft MDS using a proportion that is obtained by equally weighting the MDS's share of worldwide flying hours and possessed aircraft.

In summary, the unit personnel costs of aircrews and maintenance personnel, POL, training ordnance, and aircraft overhaul costs are directly collected at the MDS level. These categories constitute about 52 percent of total VAMOSC costs. Also, as we

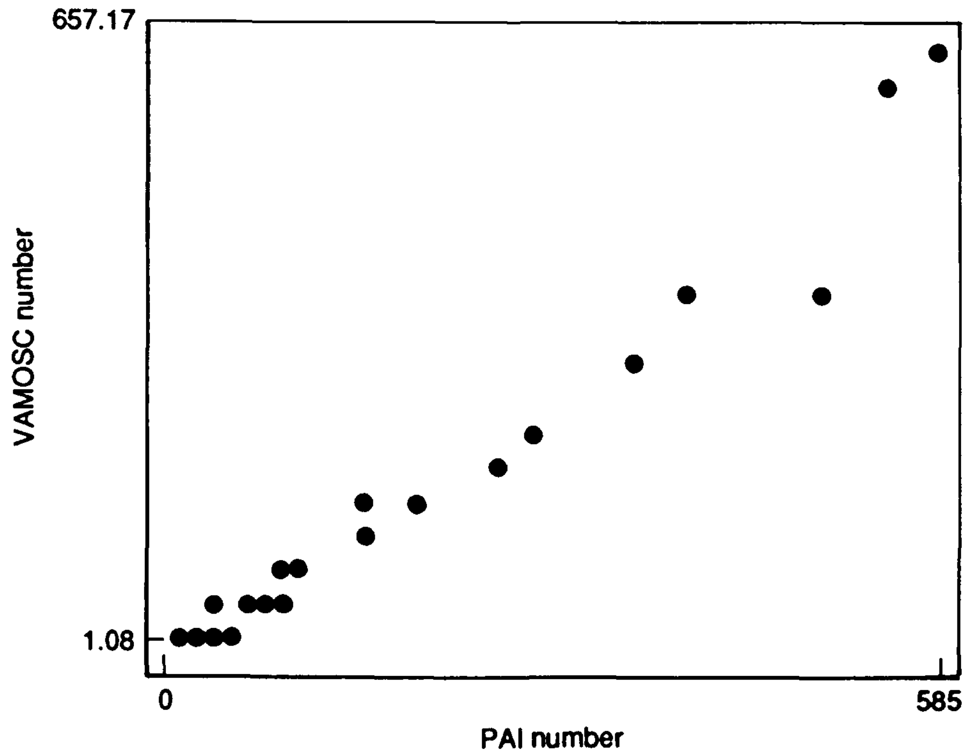

Fig. A.1—Number of aircraft in VAMOSC and PAI, 1986

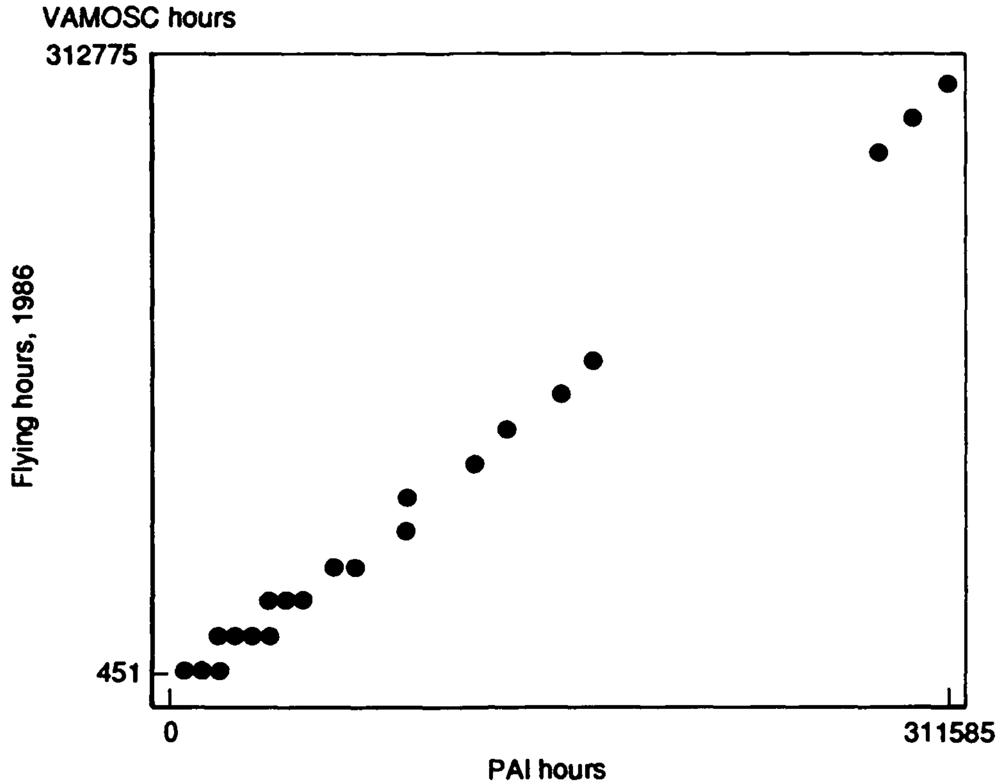

Fig. A.2—Number of flying hours in VAMOSC and PAI, 1986

have indicated above, aircraft overhaul costs are about 40 percent of depot maintenance total. Furthermore, some additional part of depot maintenance costs would be available at the MDS level.[7]

[7]Maintenance material costs are allocated to aircraft MDS using the MDS's maintenance hours share of the command/base maintenance hours. If the ratio of maintenance hours to the dollar value of the maintenance materiel is similar across command aircraft, then these costs would also be effectively identifiable at the MDS level. About 5 percent of VAMOSC costs are in the maintenance materiel category, and this would increase the unallocated costs to 57 percent of the total. We have also indicated that some additional depot maintenance costs are available at the MDS level. This would constitute about 1.5 percent of total VAMOSC costs. Also, whenever a single aircraft MDS predominates at a base, many of the base level costs can be more closely associated with that MDS. In our empirical analysis of unallocated costs, however, we have not included maintenance material or taken account of these other factors.

Unallocated Cost Regressions

As described in Fig. 6, there is a strong association identified in the data between the log of O&S costs and the log of flying hours. However, many costs are allocated using, in part, an aircraft MDS's flying hours. If the pattern represented in Fig. 6 was simply an artifact of the cost allocation process, and not derived from the accurate identification of incremental cost, the estimated coefficients of flying hours summarized in Tables 2 through 5 would be biased.

To examine this issue further, we have estimated relationships paralleling Tables 2 and 5 using as dependent variables only those costs directly collected at the MDS level. The dependent variables are successively total unallocated costs (aircrew and

Table A.13

COMPARISON OF REGRESSION INCORPORATING PAI DATA
(t-statistics in parentheses)

Dependent Variable: Log of Total O&S Costs per Aircraft		
Independent Variable	**WAMOSC Data**	**PAI Data**
Log average flying hr	.6144 (18.581)	.6116 (18.561)
Log number of aircraft	−.0367 (−3.503)	−.0353 (−3.385)
Log flyaway cost	.3916 (27.136)	.3981 (27.508)
MD Fleet Age	.0170 (7.134)	.0175 (7.354)
Year dummy (1986 = 1)	.0588 (0.111)	−.2256 (−0.390)
Year Dummy Interaction		
Log average flying hr	−.0037 (−0.046)	.0081 (0.093)
Log number of aircraft	−.0072 (−0.311)	.0321 (1.280)
Intercept	−3.8607 (−18.221)	−3.8745 (−18.350)
Adjusted R^2	.82	.82
No. Observations	400	397

maintenance unit mission personnel, POL, training ordnance, and aircraft overhaul) and aircraft overhaul costs. Table A.14 contains the regression with the total unallocated O&S costs per aircraft as the dependent variable.

With the exception that the cargo categorical variable is now statistically significant in the regression that includes all explanatory variables, the results are very similar to Table 2.[8] Of particular note is the fact that the coefficients of flying hours per aircraft and flyaway costs of Table A.14 are similar to that of Table 2. For example, Table 2 reported in the Flyaway Only regression that a 1 percent change in flying hours per aircraft resulted in a .61 percent change in total O&S costs per aircraft. Table A.14 indicated that, for the similar regression, a 1 percent change in flying hours per aircraft results in a .66 percent change in unallocated O&S costs per aircraft.

In the same comparable regressions, Table 2 indicates that a 1 percent change in flyway cost increases total O&S cost per aircraft by .39 percent, whereas Table A.14 shows that a 1 percent change in flyaway cost increases unallocated O&S cost per aircraft by .43 percent. In both regressions, therefore, the responsiveness of O&S cost per aircraft to changes in flying hours per aircraft is larger than the responsiveness to changes in flyaway cost. In other words, the qualitative pattern identified in Table 2 continues to apply in Table A.14.

One can examine other coefficients as well and note the strong similarity between the two regressions. We conclude, therefore, that the elimination of the allocated cost categories does not significantly change the pattern presented in Table 2.

We also compare the depot maintenance cost per aircraft regressions of Table 5 with comparable regressions in which the unallocated part of depot maintenance, namely aircraft overhaul cost per aircraft, is the dependent variable. The new results are contained in Table A.15.

While the coefficients of flying hours per aircraft and flyaway cost are somewhat larger in the Flyaway Only regression of Table A.15 than in Table 5, an important observation of our study remains valid—that O&S costs per aircraft become more responsive to flyaway cost and less responsive to flying hours per aircraft when disaggregating cost from the total O&S cost level to depot cost level.

[8]The coefficient of the cargo variable was negatively statistically significant in Table 4, which uses non-P&A, non-fuel O&S costs per aircraft as a dependent variable. This suggests that the significance of cargo aircraft in Table A.14 may be traced to the larger fuel component of unallocated costs.

Table A.14

UNALLOCATED TOTAL O&S COSTS PER AIRCRAFT
(t-statistics in parentheses)

Dependent Variable:
Log of Total Unallocated O&S Cost per Aircraft

Independent Variable	All Variables	Flyaway Only	No Flyaway Variable
Log average flying hr	.6285 (14.878)	.6648 (20.424)	.6618 (9.464)
Log number of aircraft	−.0163 (−1.425)	−.0274 (−2.670)	−.0312 (−1.650)
Log flyaway cost	.4275 (26.194)	.4326 (27.912)	—
Fighter-attack	.0427 (0.698)	—	.2302 (2.284)
Cargo	.1595 (2.627)	—	.4467 (4.515)
MDS IOC Year (1944 = 1)	−.0031 (−0.887)	—	.0189 (3.343)
MD Fleet Age	.0147 (3.291)	.0199 (7.817)	.0293 (3.977)
Intercept	−4.7548 −15.986)	−5.0239 (−23.994)	−4.6952 (−9.530)
Adjusted R^2	.82	.82	.54
No. Observations	400	400	400

The conclusion of Table A.15 that aircraft overhaul costs are almost proportional to flyaway cost is also reasonable. It would be expected that enhancements in reliability would have a greater effect on reducing engine and avionics depot costs than they would the costs of on-equipment aircraft overhaul. Also, the categorical cargo variable is now statistically significant in the All Variables regression, perhaps because avionics costs, which would be expected to be low for cargo aircraft, are not included in the unallocated depot maintenance aircraft overhaul dependent variable.

MD Level Regressions

As we indicated above, approximately 85 percent of the depot maintenance costs are directly identifiable at the MD level. This indicates that the cost allocation rules should not have a substantial effect on the prediction of depot maintenance costs if the cost relationship is estimated at this level.

Measurement errors for the other cost categories will not result in biased regression coeffients if these errors are uncorrelated with the explanatory variables. To examine this issue, we must consider the nature of the allocation rules discussed above.

It is apparent that the cost of many categories, such as installation support personnel and indirect personnel support, are allocated to MDS using a proportion that is constructed by giving equal weight to the MDS's share of command/base flying hours and possessed aircraft. Not only are aircraft MDS flying hours not perfectly correlated with aircraft MD flying hours, but, the denominator of the proportion, which represents other command aircraft at the base, would not necessarily include aircraft that belong to the same MD. Therefore, one would not expect the flying hours associated with these aircraft to be highly correlated with MD flying hours.

Consequently, any measurement error derived from this allocation rule should be only weakly correlated with MD flying hours, and the regression coefficient of MD flying hours should not contain any significant bias. An analogous argument would apply for the relationship between measurement error and MD possessed aircraft.

This suggests that it is appropriate to examine total O&S cost relationships that are estimated using MD level data to determine how similar these results are to those reported in Table 2. At the aircraft MD level, there are 198 observations (versus 400 at the MDS level). Table A.16 summarizes the regression results for total O&S cost per aircraft. In this and the subsequent depot maintenance cost regression (Table A.17), the variable MDS IOC Year has been replaced by the average IOC year of these MD aircraft.

If we focus on the Flyaway Only regression of Table A.16, we see that the coefficient of flying hours is slightly lower and the coefficient of flyaway cost is slightly higher than is the case in Table 2. The changes are fairly modest, however, and the qualitative relationship between the two coefficients remains as before.

If we turn now to the depot maintenance cost relationship at the aircraft MD level, and continue to focus on the Flyaway Only column, we find in Table A.17 that the

Table A.15

REGRESSION OF AIRCRAFT OVERHAUL O&S COSTS
(t–statistics in parentheses)

Dependent Variable: Log of Aircraft Overhaul O&S Cost per Aircraft			
Independent Variable	All Variables	Flyaway Only	No Flyaway Variable
Log average flying hr	.9572 (4.519)	.6630 (4.000)	.9698 (4.107)
Log number of aircraft	.0132 (0.215)	–.0477 (–0.861)	–.1022 (–1.523)
Log flyaway cost	.8091 (8.809)	.9026 (9.876)	—
Fighter-attack	1.4994 (4.938)	—	1.7553 (5.210)
Cargo	.8934 (2.998)	—	1.0948 (3.306)
MDS IOC year (1944 = 1)	.0144 (0.873)	—	.0497 (2.780)
MD fleet age	.0771 (3.722)	.0311 (2.366)	.0892 (3.869)
Intercept	–13.4111 (–8.992)	–9.6009 (–8.384)	–11.9399 (–7.228)
Adjusted R^2	.37	.32	.21
No. Observations	323	323	323

coefficient of flyaway cost is reduced and that of flying hours has increased from that of Table A.17. Therefore, the same qualitative coefficient shift occurred between Table 2 and Table 5.

Although the coefficients of flying hours and flyaway cost in Table A.17 are now somewhat smaller and larger, respectively, than those of Table 5, we continue to find that increases in flyaway cost result in less than proportional increases in depot maintenance O&S costs per aircraft.

We also investigated the effect of the allocation rules using a somewhat different methodology. As we have indicated above, it is possible to cast the cost allocation issue in terms of dependent variable measurement error. If the allocation rules lead to measurement errors that are uncorrelated with the explanatory variables—that is, if the

Table A.16

TOTAL O&S COSTS AT THE MD LEVEL
(t–statistics in parentheses)

Dependent Variable: Log of Total O&S Cost per Aircraft			
Independent Variable	All Variables	Flyaway Only	No Flyaway Variable
Log average flying hr	.5199	.5412	.7793
	(7.093)	(11.376)	(6.127)
Log numbers of aircraft	−.0724	−.0731	−.0924
	(−4.913)	(−5.252)	(−3.564)
Log average flyaway cost	.3785	.3873	—
	(20.091)	(23.206)	
Fighter-attack	−.0091	—	.4006
	(−0.116)		(3.006)
Cargo	−.0106	—	.3769
	(−0.145)		(3.022)
MD average IOC (1944 = 1)	.0074	—	.0290
	(1.578)		(3.560)
MD fleet age	.0143	.0076	.0233
	(2.486)	(2.248)	(2.300)
Intercept	−3.1877	−3.0634	−4.7056
	(−6.729)	(−10.025)	(−5.707)
Adjusted R^2	.86	.86	.56
No. Observations	198	198	198

measurement errors are random—then the regression coefficients would remain unbiased. Suppose, however, that the measurement errors are correlated with the flying hours and possessed aircraft explanatory variables. Then, the estimated coefficients of these variables would be biased. One might suggest an approach in which flying hours and possessed hours are purged of their dependence on the measurement error by first regressing these variables on a set of instrumental variables. These instrumental variables would need to be both highly correlated with flying hours and possessed aircraft and simultaneously uncorrelated with the measurement error. One possible set of instrumental variables would be the aircraft type and MDS IOC year variables. We investigated this two-stage least squares regression approach by first obtaining predicted values of the log of flying hours and possessed aircraft by regressing these variables on

the instrumental variables. We would expect such predicted values to be only weakly correlated with the error term of the regression model. In the second stage, we regressed total O&S costs per aircraft on the predicted values of these two variables and the remaining variables of the Flyaway Only regression of Table 2. We find the estimated coefficients of this two-stage least squares regression to be very similar to those of Table 2. This supports the view that measurement error is not a serious problem. For our purposes, the allocation rules are accurate, and it is reasonable to conclude that the estimated coefficients of the explanatory variables measure real rather than artificial changes in O&S costs.

The regression results for unallocated costs support the basic results obtained in this study. Less than half of total costs are allocated based on aircraft MDS flying hours and numbers of possessed aircraft. Although there may be a concern that the coefficients of flying hours are strongly influenced by the allocation rules, we continue to find this coefficient significant when attention is focused on unallocated costs. Furthermore, the same qualitative pattern identified in the main body of the text continues to apply. When we compare the MDS regression of Tables 2 and 5 with the MD regression of Tables A.16 and A.17, we again obtain a similar qualitative pattern. The use of an instrumental variable approach also validates our use of the entire data base.

In summary, the allocation rules do not seem to have affected the broad character of the cost estimating relationships reported in the text. This indicates that they have not distorted the incremental cost estimates of VAMOSC, adding to the confidence one has in the explanatory power of the cost estimating relationships.

Table A.17

TOTAL DEPOT MAINTENANCE COSTS AT THE MD LEVEL
(t–statistics in parentheses)

Dependent Variable:
Log of Depot Maintenance Cost per Aircraft)

Independent Variable	All Variables	Flyaway Only	No Flyaway Variable
Log average flying hr	.4021 (3.134)	.2286 (2.579)	.9432 (3.736)
Log number of aircraft	–.0427 (–1.656)	–.0384 (–1.481)	–.0844 (–1.641)
Log average flyaway cost	.7894 (23.937)	.8478 (27.259)	—
Fighter-attack	.3277 (2.391)	—	1.1823 (4.470)
Cargo	–.1085 (–0.845)	—	.7000 (2.827)
MD average IOC (1944 = 1)	.0333 (4.009)	—	.0781 (4.834)
MD fleet age	.0581 (5.755)	.0173 (2.731)	.0769 (3.819)
Intercept	–7.361 (–8.876)	–4.9472 (–8.687)	–10.5274 (–6.433)
Adjusted R^2	0.85	0.83	0.41
No. Observations	198	198	198